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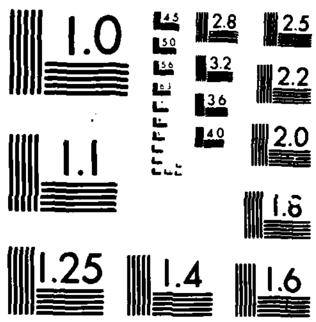

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number):

This report investigates and recommends methods of adaptively controlling parameters of Spread Spectrum Communication links to achieve Low-Probability-of-Intercept for a network composed of many links. The results provide an informative insight into the interaction between link/network variables. The best choice of parameter values for optimization of tactical situations for the communicators and/or the interceptor may be made based on algorithms developed. Recommendations for further research are included.

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ON ACHIEVING NETWORK LPI
FOR SPREAD SPECTRUM COMMUNICATIONS

FINAL TECHNICAL REPORT

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FINAL TECHNICAL REPORT

ON ACHIEVING NETWORK LPI FOR SPREAD SPECTRUM COMMUNICATIONS

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EXECUTIVE SUMMARY

The objective of this report is to advance the U.S. Army research program in adaptive control of distributed spread spectrum radio networks. Under contract to the U.S. Army Research Office, Research Triangle Park, North Carolina, the Melpar Division of E-Systems has conducted a one-year study entitled "On Achieving Network LPI for Spread Spectrum Communications" to investigate and recommend methods of adaptively controlling parameters of spread spectrum communication links to achieve overall LPI for a network composed of many such links. The results provide an informative insight into the interaction between link/network variables. The best choice of parameter values for optimization of tactical situations for the communicator and/or the intercepter may be made based on algorithms developed. Recommendations for further research are included.

Under this effort four tasks were performed. The first three were analytical in nature while the fourth was qualitative. Mathematical models have been developed based on the fundamental parameter relationships found in DSE Spread Spectrum links and networks. These computer models provide numerical results for realistic values of system parameters. Graphs and "snapshots" of these results have been formulated to facilitate presentation. Models developed under tasks one, two, and three are described below and papers which detail these models are being presented for publication to several well-known and respected trade journals. Abstracts of these papers are included as an addendum to this report.

1.0 INTRODUCTION

1.1 OBJECTIVE

The objective for conducting the investigation of link/network parameters under this contract was to analyze and bound the interaction between key variables, treating each as a resource from which a tactical UHF direct sequence spread spectrum communication network might draw real-time information to use to adaptively control its own probability of intercept. This information could be used in designing communication systems which deny or degrade anticipated capabilities of adversarial SIGINT and EW assets. Continued effort under subsequent contracts is expected to identify technological areas critical to the development of reliable and efficient communication systems based upon adaptive network control strategies.

The purpose of this Final Technical Report is to document the findings and recommendations which have resulted from this contract.

1.2 SCOPE

U.S. Command and Control Communications (C^3) can be attacked using a variety of C^3 Counter-Measures (C^3CM). During the past decade, we have witnessed the effectiveness and efficiency of foreign SIGINT and EW equipments in military engagements worldwide.[1,2,3] The experience gained would be abandoned if effective measures were not taken to protect the lifelines of our tactical fighting forces. The scope of this effort was tailored to the contract objective of identifying the combinations of variables necessary to achieve protection from adversary attacks on our C^3 systems.

1.3 APPROACH

There were two major components of the approach used to investigate parameter interaction within a tactical communications and signals intelligence environment. The first component was to identify the key parameters, model their interaction, and quantify their effects on communication and intercept ranges. The second component was to generate scenario snapshots on a macroscopic level bounding parameter interactions in a form which may be better understood. The essence of this report is the mutually supporting results of these two components. The investigative approach is depicted in Figure 1.1.

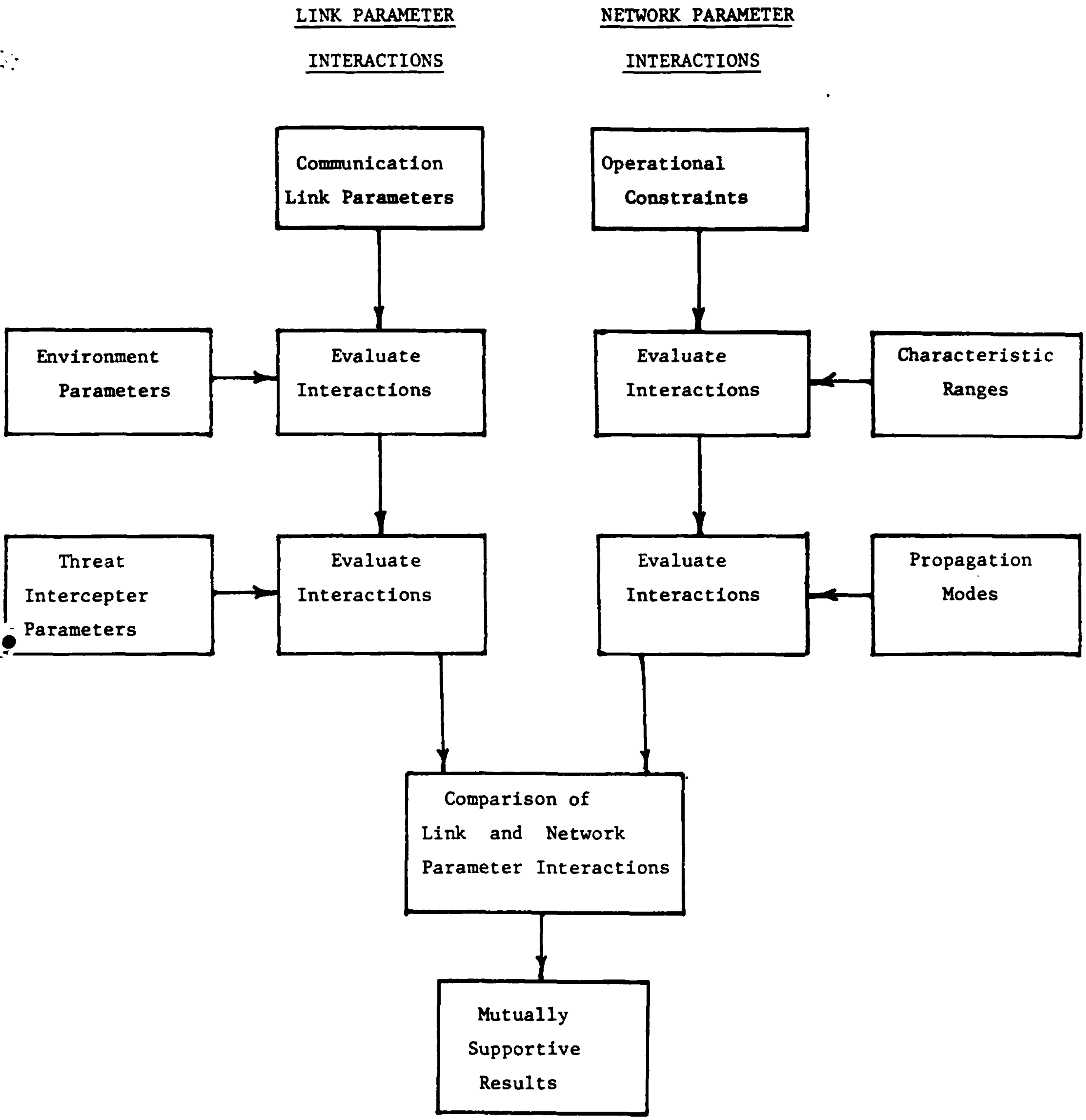


Figure 1.1 The Approach Provides Complementary Components

2.0 BACKGROUND

2.1 COMMAND AND CONTROL COMMUNICATIONS

The Air Land Battle 2000 concept proposed for the Army of the 21st Century espouses a highly mobile battlefield in which commanders will be charged with the orchestration of tactics involving the coordinated services of multiple branches of our armed forces. The command and control needed to organize these forces will be carried over tactical communication systems. With strong reliance on the individual commander's initiative and the requirement for rapid reconstitution of forces after an engagement, the dependence on survivable command and control communications (C^3) cannot be overemphasized.

Spurred into action by the rediscovery and rewording of the C^3CM concept calling for integration and coordination of the major techniques of modern warfare, the U.S. has stepped-up its development of tactical communication systems. These initial ECCM communication systems included: HAVE QUICK, SEEK TALK (now Enhanced JTIDS), Combat Identification System (CIS), JTIDS, JRSVC (now combined with Enhanced JTIDS), and SINCGARS. Interest also increased in how information might best be formatted, distributed and manipulated in military communication networks. One powerful concept developed in this area was packet transmitting and switching which promised increased signalling flexibility on a network basis. Refinements and research continue in this area.

Although there are a variety of methods available for achieving AJ protection, spread spectrum modulation techniques have formed the cornerstone of virtually every AJ system developed by the U.S.

The development of spread spectrum techniques primarily for AJ has not only reduced the risk in applying these techniques to operational ECCM systems but has also increased the level of awareness of what spread spectrum modulation can achieve in the area of LPI radio communications. Of particular importance now is how the variable parameters of a spread spectrum LPI radio might be adjusted to improve the overall level of LPI for a network of radios.

2.2 SOVIET C^3 COUNTERMEASURES

The Soviets are well acquainted with the theory and practice of AJ communications as their troops are exposed early and repeatedly to EW exercises. A study of Soviet unclassified and open patent applications and literature reveals that they understand the technical issues required both to develop[4,5] and to exploit[6] sophisticated spread spectrum C^3 systems.

An assessment of the requirements for survivable communications and an increased awareness of the Soviet Radio Electronic Combat (REC) capabilities can be gleaned from SIGINT and EW successes witnessed during the 1973 Yom Kippur War and many other military actions since. REC capabilities include numerous radio frequency intercept, radio direction finding, and communication jamming assets, as well as, signal fusion, correlation, templating, critical node analysis and "hard kill" targeting.

2.3 U.S. RESPONSE

In 1976, a Task Force of the Defense Science Board addressed the subject of a conventional attack by the Warsaw Pact against NATO. A key aspect of the engagement was the great numerical superiority of the Soviet forces. Of the four major recommendations made by the Task Force, one finding focused on the importance of protecting the C^3 systems which command, control and coordinate the actions of our own tactical forces. The rationale was that good C^3 is a "force multiplier" for us and would help offset the numerical superiority of the enemy. In 1977 the DSB Task Force on Countering Warsaw Pact C^3 was formed. The Task Force Report was reviewed by a DoD Committee chaired by Adm. Murphy, U.S.N. (Ret.). The Murphy Committee report was released in 1979 and among the results was DoD Directive 4600.4. This directive defines C^3CM as "the integrated use of operations security, military deception, jamming, and physical destruction, supported by intelligence, to deny information to, influence, degrade, or destroy adversary C^3 capabilities and to protect friendly C^3 against such actions".

2.4 TIMETABLE

The Army's need for survivable C^3 on today's battlefield is the catalyst behind the rapid development of AJ and LPI systems. Spread Spectrum techniques have been identified as a key component of these systems. It has been shown that spread spectrum techniques can provide a measureable degree of survivability against conventional narrowband SIGINT and EW systems.[7] The concern now expressed by friendly users of C^3 systems is the systems' ability to survive in a rapidly changing environment in which the threat displays a dynamic component to overcome the advantages afforded by static spread spectrum systems. This idea of applying an adaptive C^3 response to a changing threat is the subject of current research in ECCM and LPI for Radio Networks.[8] The survivability of our C^3 systems, and hence, our national security, is dependent on implementation of adaptive control/artificial intelligence in these newly developed communication systems. As such, this task is time critical and must be addressed and a solution must be found at the earliest possible date.

3.0 ANALYSIS

3.1 KEY LINK PARAMETERS

3.1.1 ADJUSTABLE PARAMETERS IN THE LINK EQUATION

To develop the adaptive control strategies that allow robust communication network management it is necessary to thoroughly understand interaction between key parameters in both the communication link and network. As the adjustable parameters within a link are often interdependent it is necessary to determine the ideal combination of variables to achieve the maximum connectivity range to the intended receiver while minimizing the maximum range available to an interceptor. Link geometry for any communication channel in the field is expected to be relatively dynamic. Freezing the action might give the situation depicted in Figure 3.1

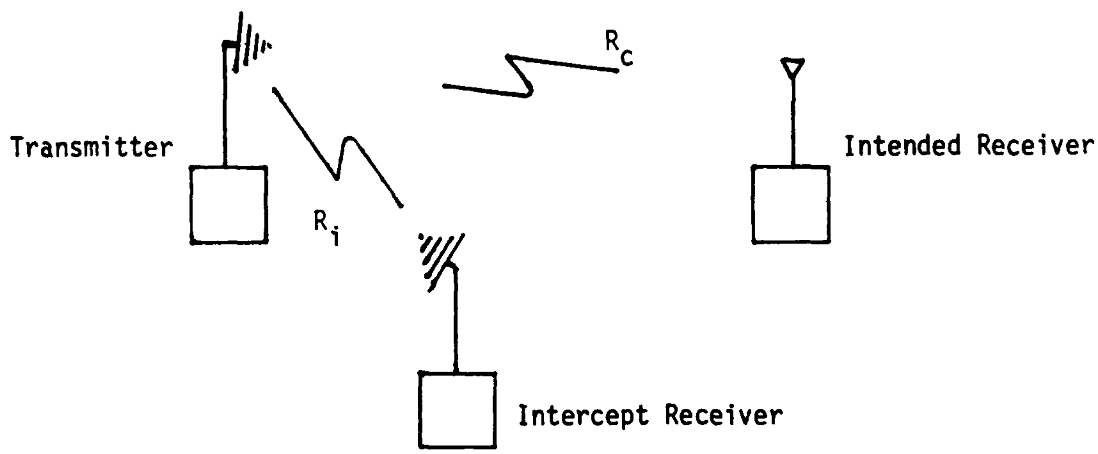


Figure 3.1 Expected Communication Link Geometry

Adaptive control over the link might be exercised by the transmitter, the receiver(s) and/or a transmitter-receiver pair. An analysis of the link equation is given in Appendix A.

Those terms attributable to and controllable solely by the transmitter are the transmitted power and the transmitter antenna gain in the direction of the friendly and/or intercept receiver.

$$f\ (Tx) = P_t\ G_t$$

where,

P_t, the power transmitted, is described as the product of the bit energy , Eb, and the average source information rate, r_b. Since effective aperture size and gain are related by

$$G_t = 4\pi n\ A_e\ /\lambda^2$$

where,

A_e is the effective antenna aperture (in square meters),

n is the antenna radiation efficiency of an aperture type antenna (unitless),

and,

λ is the wavelength of the center frequency of operation, the gain attributable to the transmitting antenna is a function of the effective aperture, the radiation efficiency and the wavelength/frequency of operation.

Those terms attributable to and controllable by the friendly and/or intercept receiver are:

$$f\ (Rx) = G_r\ /\ L_r$$

where,

G_r is the antenna gain at the receiver end of a link in the direction of the transmitter,

and,

the term L_r is for the losses /attenuation of the signal due to the receiver design and is not considered to be easily changed by an operator.

Whether the receiver is the intended or an interceptor makes no difference in using unilateral adaptive control as one must contend with the same physical laws of nature. As with the transmit antenna gain, the receive antenna gain is

related to effective aperture size, radiation efficiency and wavelength by

$$G_r = 4\pi n \ A_e / \lambda^2$$

The remaining terms are referred to as link terms and are attributable to and controllable only by cooperative transmitter-receiver pairs which comprise the link.

$$f(L) = K / (4\pi R/\lambda)^2 R^{a-2}$$

where,

lambda is the wavelength of the center/carrier frequency chosen for link operation. It can be determined from the frequency by $\lambda = c/f$ where c is the speed of light, 3×10^8 meters/sec, and f is the frequency measured in Hertz.

K is the signal suppression factor, a constant of attenuation determined by the choice of transmission bandwidth, W_{ss}, and receiver baseband bandwidth, W_{bb}.

R is the distance between transmit and receive antennas (in km),

a is the propagation mode term which is equal to 2 for free space propagation and is equal to 4 for typical groundwave propagation,

and the squared term in the denominator is the free space loss/attenuation.

A commonly accepted form of the free space loss equation in dB is

$$FSL = \left[(4\pi Rf / c)^2\right]_{db} + L_{m_{db}}$$

where,

L_m is the atmospheric attenuation in dB (assumed equal to zero for the earth's atmosphere.)

R is the range,

f is the center frequency of operation, and

c is the speed of light.

Use of the Longley-Rice propagation model for "Radio Transmission Loss Over Irregular Terrain" provides propagation loss below that of the free space field based on antenna heights, transmitter ERP, polarization, frequency, soil conductivity, soil permittivity, the surface refractive coefficient and type terrain (radiogeology) effects.

The general link connectivity equations therefore show that the received signal power at the input to a receiver is a function of:

- The transmitted power
- Transmit and receive antenna gains
- Transmit and receive antenna heights
- Distance between transmit and receive antennas
- Frequency and bandwidth of operation
- Transmitter and receiver hardware implementation losses, and
- Path loss effects due to ground parameters such as refractivity, terrain radiogeology, permittivity, conductivity, etc.

Table 3.1 lists those link parameters found in a communication system which are considered to be controllable under specific conditions as described previously. Likewise, Table 3.2 lists other link parameters which are not considered readily controllable by the transmitter, receiver, or by a transmitter-receiver pair.

- Center frequency of operation
- Transmitted power
- Antenna gain in the direction of the receiver (for the transmitting antenna)
- Antenna gain in the direction of the transmitter (for the receiving antenna)
- Transmitter antenna height
- Receiver antenna height
- Spread Spectrum bandwidth (chipping rate)
- Baseband bandwidth
- Polarization of the transmit antenna
- Polarization of the receive antenna
- Distance between transmit and receive antennas
- Data rate
- Antenna effective area
- Antenna radiation efficiency
- Type modulation

Table 3.1 Controllable Link Parameters in Communication Systems.

Ground conductivity
Ground permittivity
Ground refraction constant
Average terrain radiogeology
Receiver noise figure
Receiver loss

Table 3.2 Uncontrollable Parameters in Communication Systems.

The key parameters in a communication link are addressed individually in the following section.

3.1.2 INDIVIDUAL PARAMETERS

3.1.2.1 ANTENNA DIRECTIVITY, HEIGHT, AND POLARIZATION

A key element in the design of a communication system and/or a radio frequency intercept system is the antenna. Its impact on the operational flexibility of the entire system is quite significant. It is fair to say that the ultimate success of the communication link is determined more by the antennas than by any other single category of equipment in the system.[9] In this investigation antenna directivity, height and polarization were examined and their effects on other communication link parameters quantified. Figure 3.2 a* and b* provide insight into linear intercept receiver performance as a function of the directivity of the transmit and receive antennas. It can be shown both graphically and analytically that the received signal power is directly affected by the antenna gains.

Using decibel units in the link equation(s) (1 and 2 of Appendix A) gives

(1) $S, Q = (P_t)_{dBm} + (G_t)_{dB} + (G_r)_{dB} + (K)_{dB} + (H)_{dB} - (FSL)_{dBm} - (L)_{dB} - (L_e)_{dB}$

where, S and Q are defined as the signal power at the input to the friendly and intercept receivers, respectively,

- P_t is the power transmitted in decibels referred to one milliwatt,
- G_t and G_r are the transmitter and receiver antenna gains respectively in decibels,
- K is the interference suppression factor in decibels,
- H represents the antennae height-gain function(s) **
- FSL is the free space attenuation/loss
- L is the receiver hardware implementation loss, and
- L_e is the excess loss which is due to a combination of several ground and environment variables. **

Figure 3.3* depicts the relative change in the signal-to-receiver-sensitivity vs. antenna height for transmit powers of 10 and 100 watts for an air-to-ground intercept link. The significance of this graph is that it

* Tabular data used to generate these graphs is available in Appendix B.

** Note that the quantity $(H)_{dB}-(Le)_{dB}$ is often referred to as K_c or K_i.

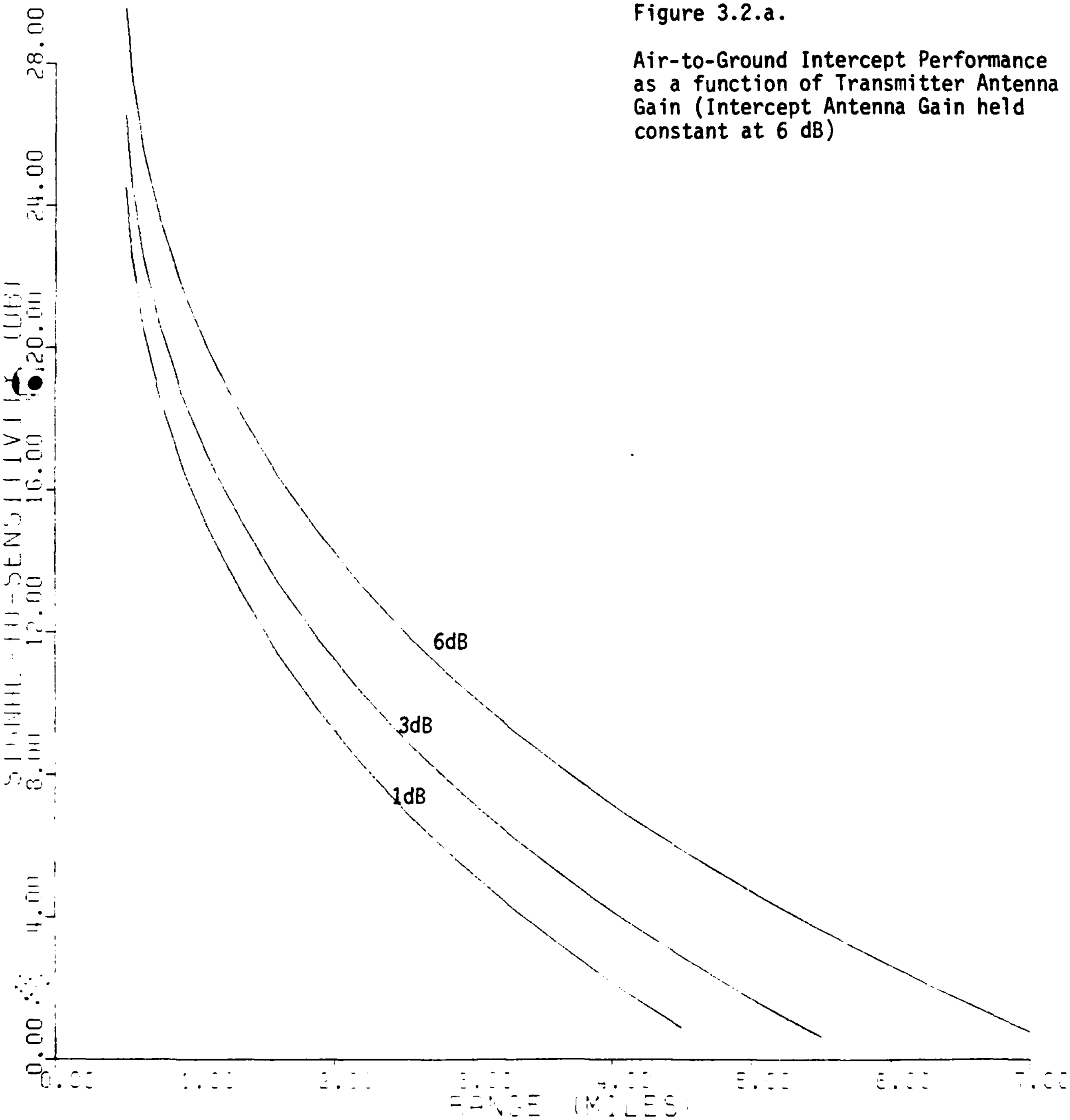


Figure 3.2.a.

Air-to-Ground Intercept Performance as a function of Transmitter Antenna Gain (Intercept Antenna Gain held constant at 6 dB)

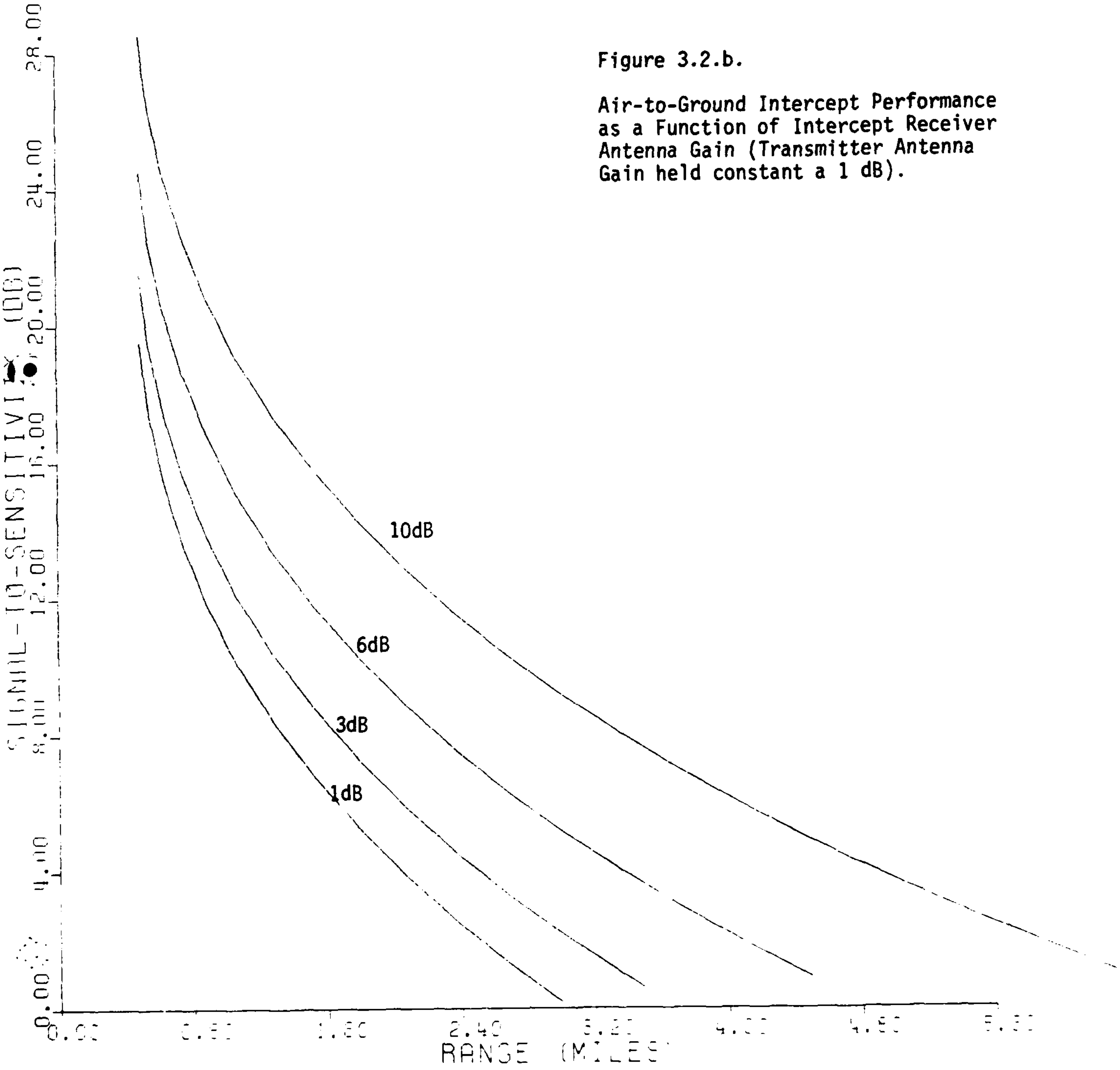


Figure 3.2.b.

Air-to-Ground Intercept Performance as a Function of Intercept Receiver Antenna Gain (Transmitter Antenna Gain held constant a 1 dB).

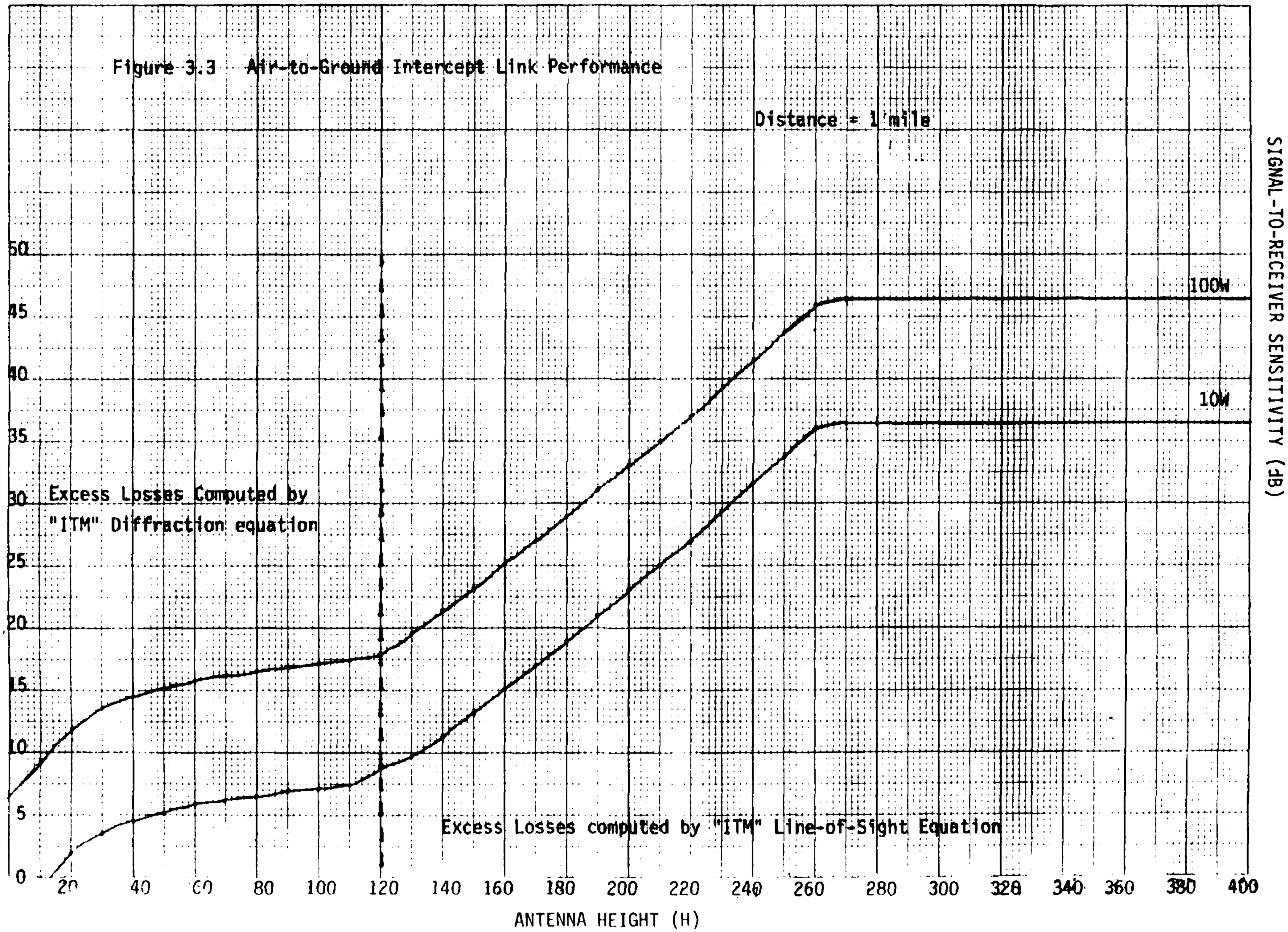


Figure 3.3 Air-to-Ground Intercept Link Performance

demonstrates the capability of an intercepter to overcome the relative gain advantage of using direct sequence spread spectrum encoding (DSE) in a communication system by raising his antenna to the appropriate height. From (1) above it can also be seen that S and Q are directly increased as a function of antenna heights (in dB).

Figure 3.4a* shows the effects of antenna polarization on the Signal-to-Receiver Sensitivity as a function of range for a typical set of DSE Communication link parameters on a ground-to-ground link. As expected, a horizontally polarized signal over a groundwave path is attenuated much more than the corresponding vertically polarized signal. In situations where the intercepter is further from the transmitter than the intended receiver this information could be very useful (assuming the communication link can change transmit and receive antenna polarizations). By comparing Figure 3.4a with 3.4b* it can be seen that the polarization effect is negligible at higher operating frequencies.

3.1.2.2 FREQUENCY AND BANDWIDTH

The link parameters of Frequency and Spread Spectrum Bandwidth can be used by transmitter-receiver pairs to enhance communication system performance while minimizing the range over which an intercepter may reliably perform his mission of exploiting the link. Figure 3.5 a*, b*, and c* show the performance of a Ground-to-Ground Communication Link, a Ground-to-Ground Intercept link and an Air-to-Ground Intercept link, respectively, for varying frequencies. It should be noted that as the center frequency of operation of a link is increased, the signal-to-receiver sensitivity (as a function of range to the transmit antenna) decreases. Close comparison of Figures 3.5 a,b,and c reveals, for example, that a groundwave communication link operating at 300 MHz can communicate out to a distance of 6 miles. A ground based linear intercept receiver would have to be approximately 2 miles from the transmitter to exploit the communications link; whereas, an airborne linear intercept receiver would be able to exploit the same transmission from a distance of 5 miles. Thus, it can be shown that the operating frequency of a spread spectrum DSE communication link can have a significant impact on not only the communication range, but also on the range over which the signal might be intercepted.

* Tabular data used to generate these graphs is available in Appendix B.

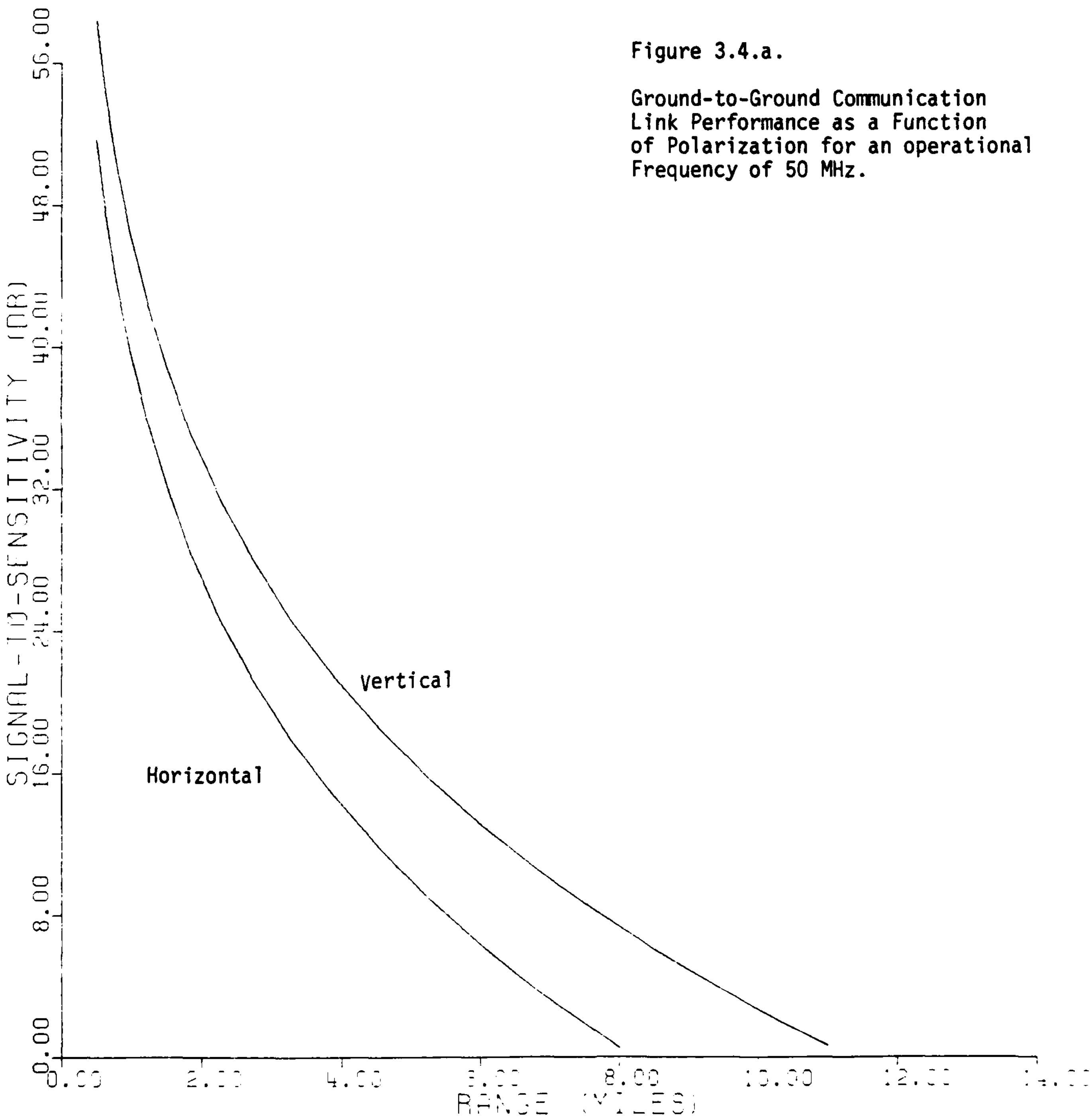


Figure 3.4.a.

Ground-to-Ground Communication Link Performance as a Function of Polarization for an operational Frequency of 50 MHz.

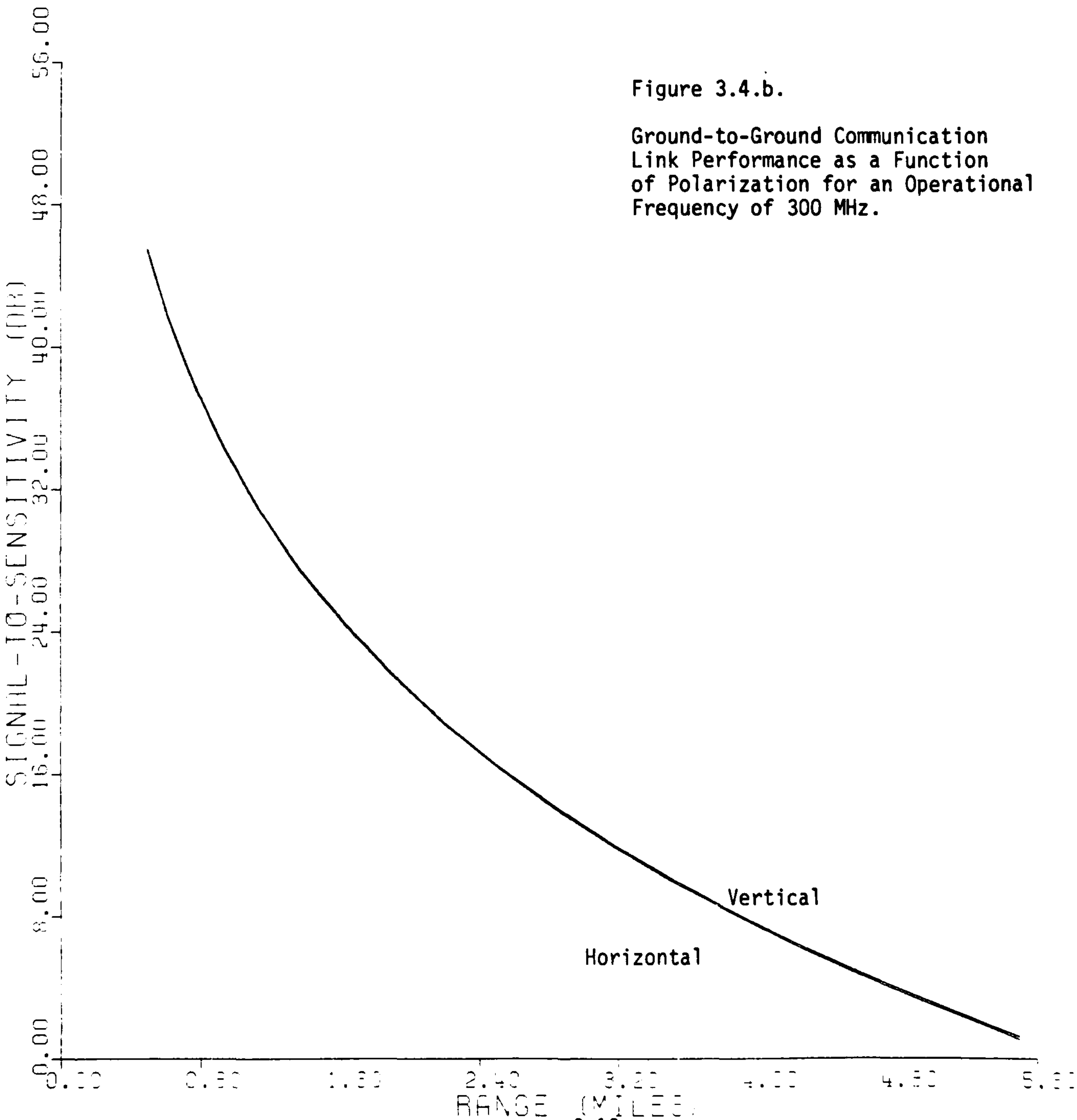


Figure 3.4.b.

Ground-to-Ground Communication Link Performance as a Function of Polarization for an Operational Frequency of 300 MHz.

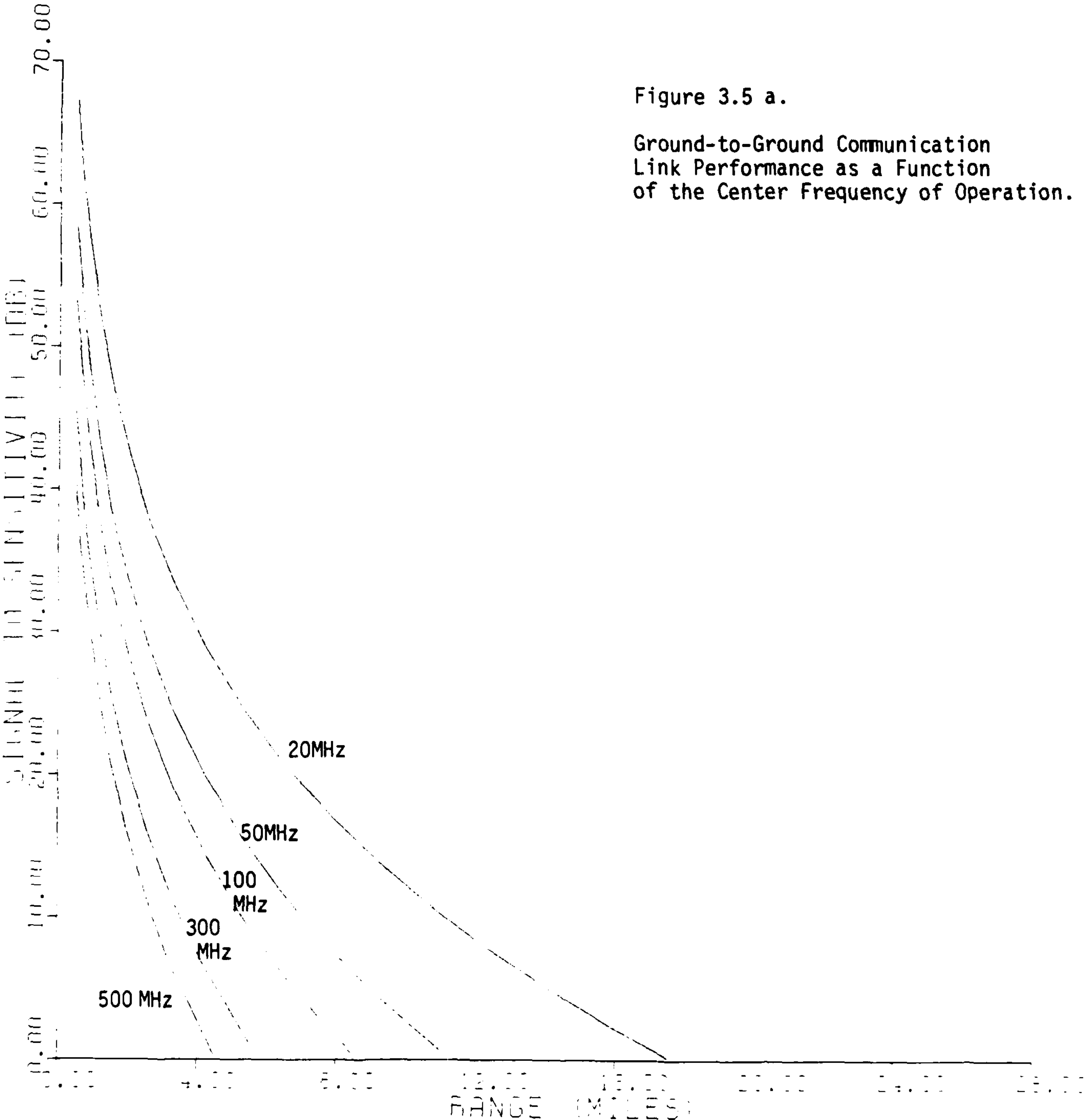
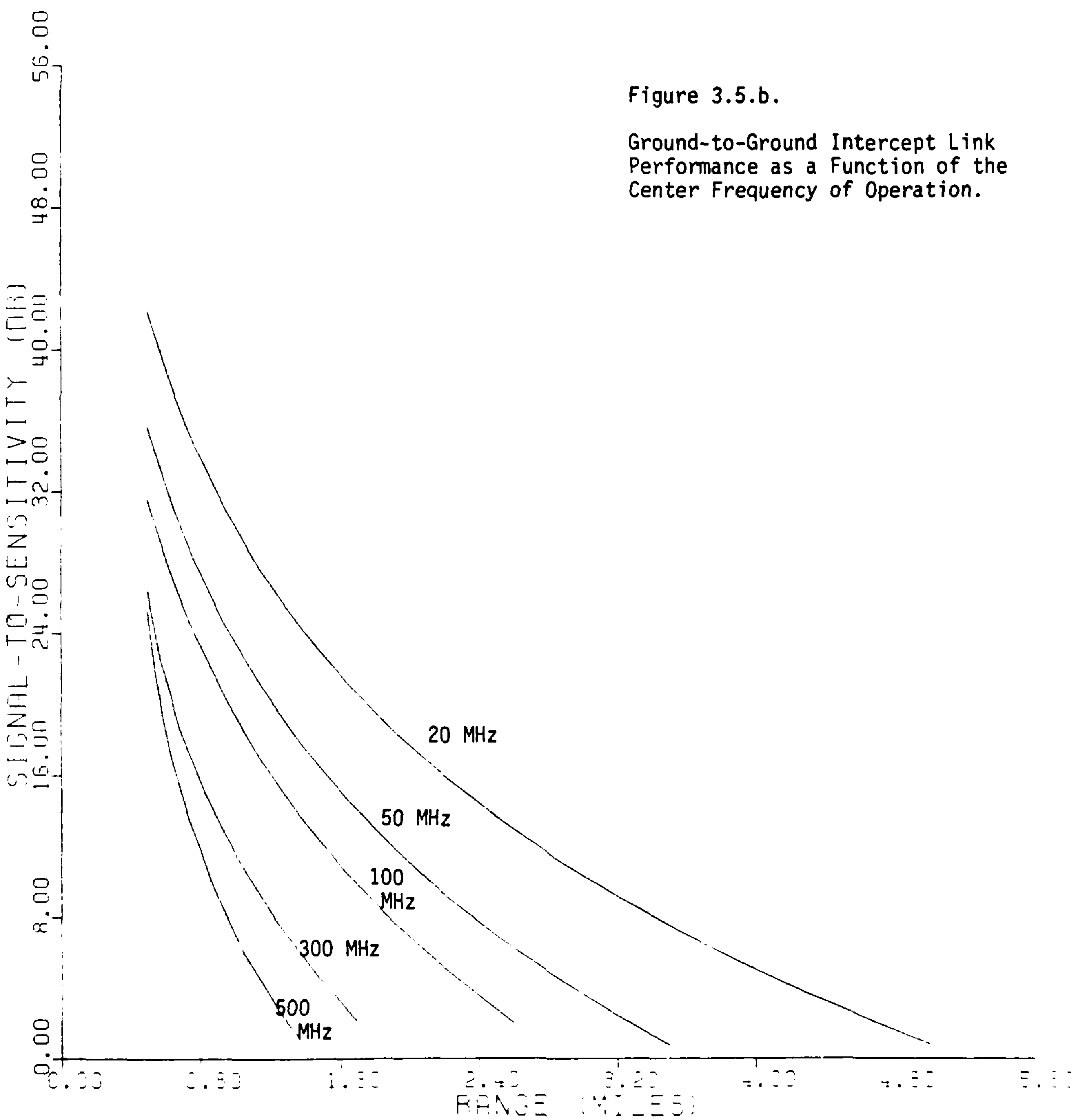


Figure 3.5 a.

Ground-to-Ground Communication Link Performance as a Function of the Center Frequency of Operation.

Figure 3.5.b.

Ground-to-Ground Intercept Link Performance as a Function of the Center Frequency of Operation.



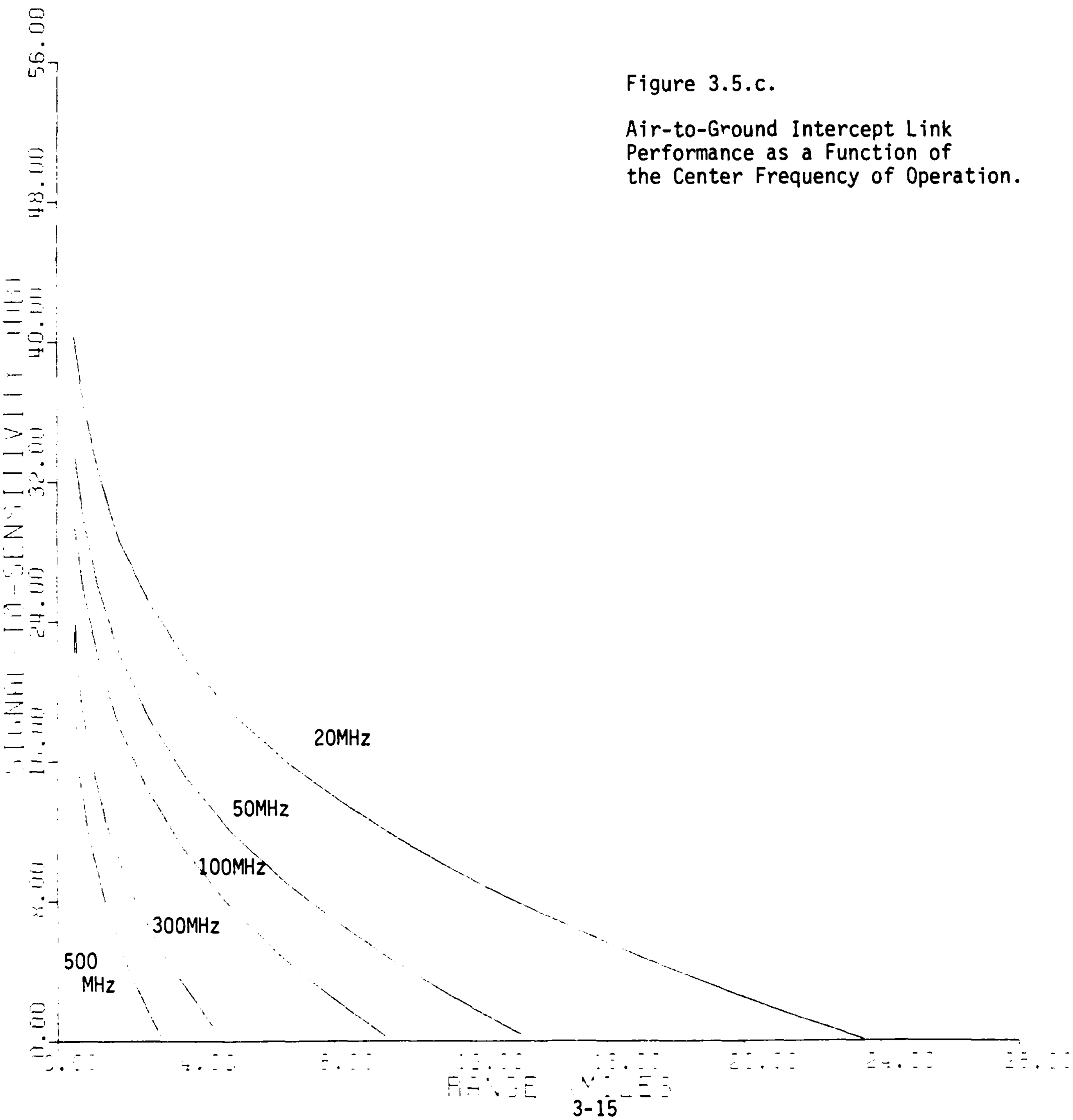


Figure 3.5.c.

Air-to-Ground Intercept Link Performance as a Function of the Center Frequency of Operation.

Likewise, an analysis of the spread spectrum bandwidth chosen for communication system operation can be adaptively used to affect the intercept distances. Figures 3.6 a* and b*, are graphs of the Ground-to-Ground and Air-to-Ground Intercept, respectively, of DSE transmissions as a function of the Spread Spectrum bandwidths used. As the DSE bandwidth increases, each graph shows a significant decrease in the intercept range. For example, using a 1 MHz bandwidth will allow approximately a 5.5 mile ground intercept distance and a 20 mile air-to-ground intercept distance; whereas, increasing the bandwidth to 100 MHz will decrease the ground intercept distance to approximately 2.5 miles and will decrease the air-to-ground intercept distance to approximately 5 miles. In comparison, the ground-to-ground communication link distance of 5.5 miles and the ground-to-air communication link distance of 21.0 miles will not be affected by changes in the spread spectrum bandwidth.

Combinations of frequency and bandwidth can be chosen by a transmitter-receiver pair to optimize the range of communications while minimizing the intercept range.

3.1.2.3 TRANSMIT POWER

Control of transmit power is a classical technique used by tactical communicators since radios were first introduced into military forces. Figures 3.7.a* and b* show the effects on Ground-to-Ground and Ground-to-Air communications links, respectively. Likewise, Figures 3.8.a* and b* show the effects on Ground-to-Ground and Air-to-Ground linear receiver intercept links for the same transmit power settings. Assuming a communicator desires to pass traffic to a receiver 5 miles distant from his position, the options available could have a significant impact on his transmitter's battlefield life expectancy. Figure 3.7.a. shows that using a 100 w transmit power for this link he may pass his message directly to his intended receiver located 5 miles away. Unfortunately, Figure 3.8.a. shows that a Ground based intercepter would be able to intercept the transmission up to approximately 2 miles away from the transmitter and, even worse, Figure 3.8.b. shows that an Airborne intercepter would be able to intercept the transmission up to approximately 5 miles distance. However, if the communicator chose to have an airborne platform relay his transmission to his intended receiver then Figure

* Tabular data used to generate these graphs is available in Appendix B.

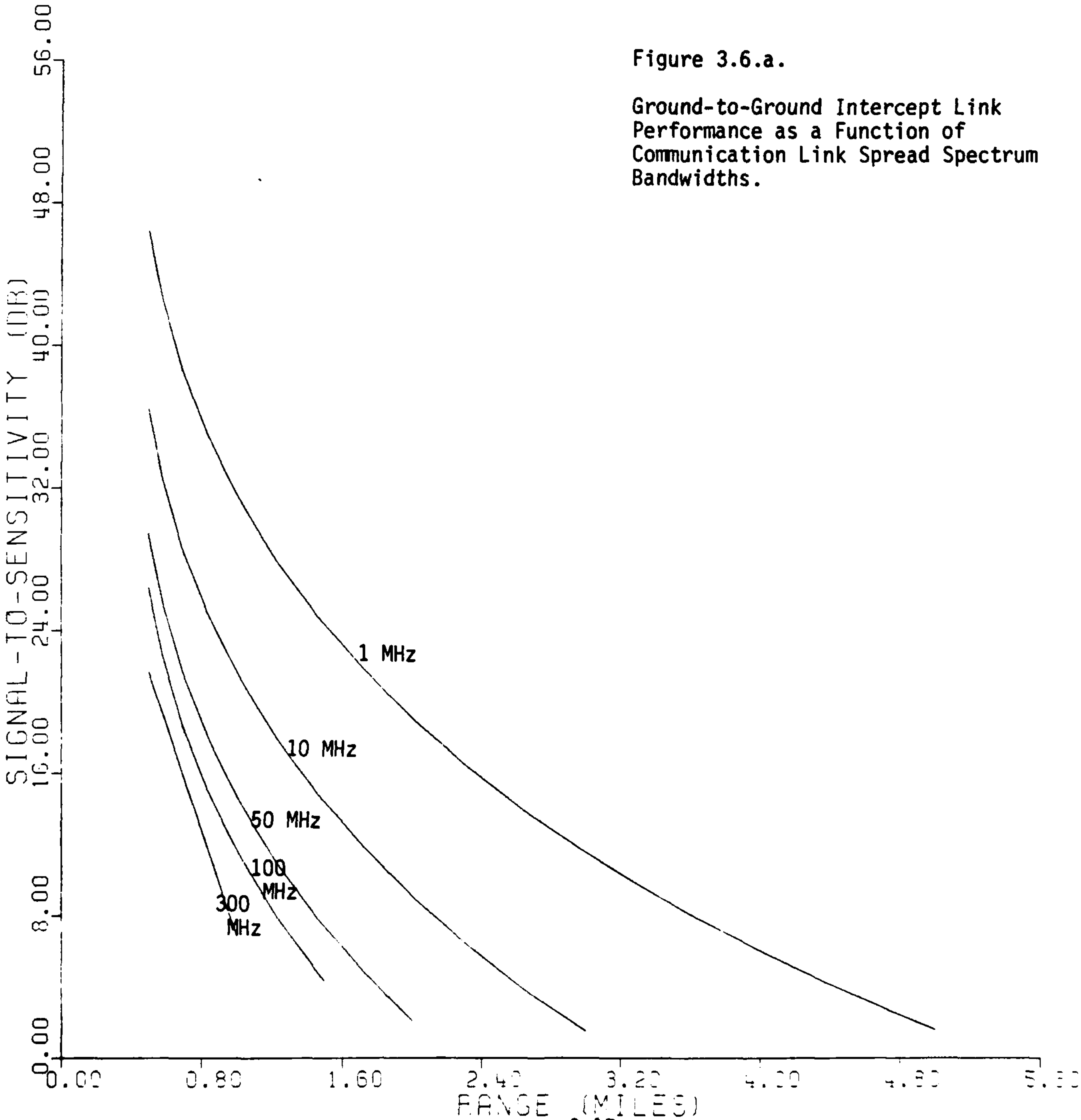


Figure 3.6.a.

Ground-to-Ground Intercept Link Performance as a Function of Communication Link Spread Spectrum Bandwidths.

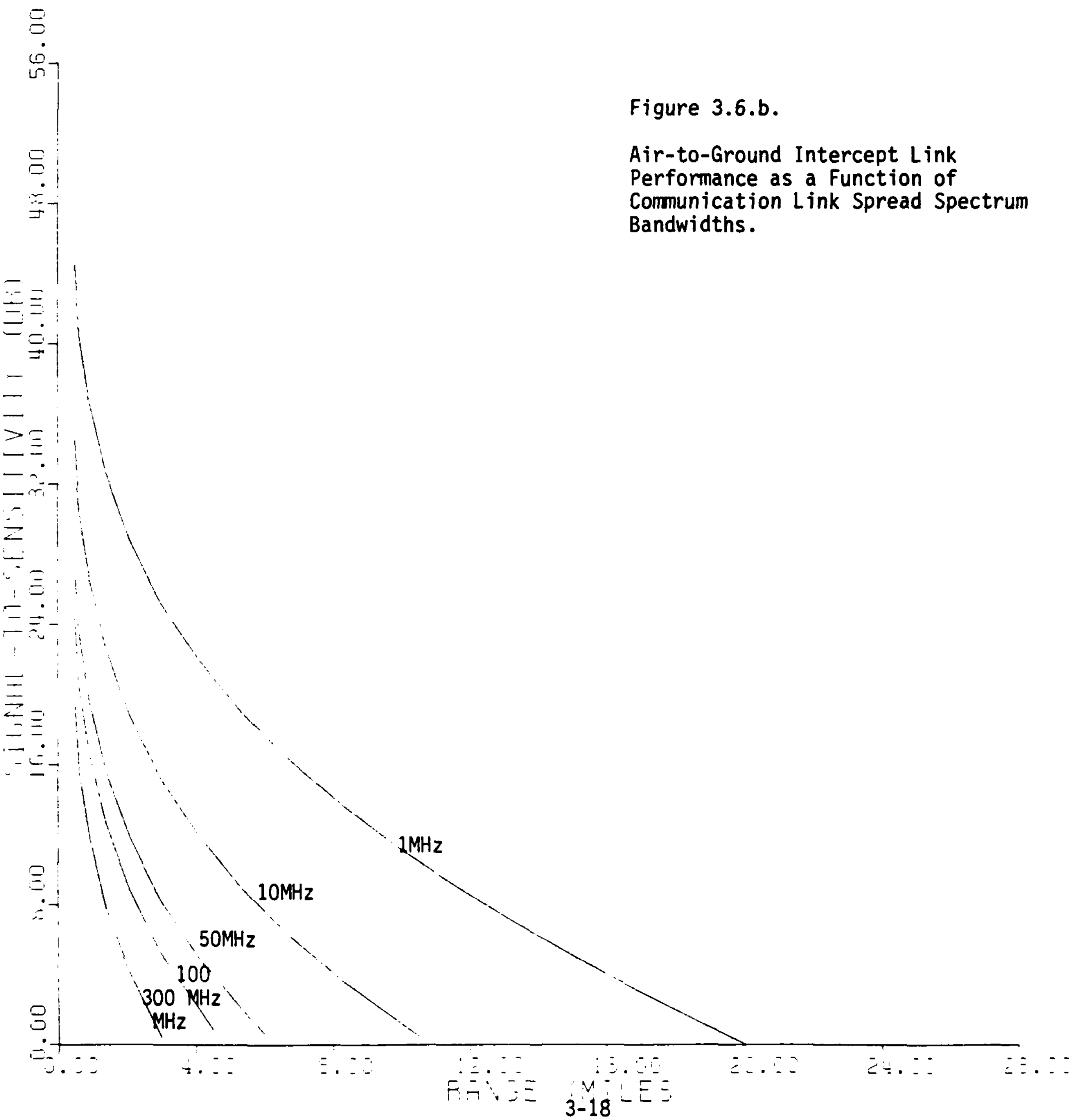


Figure 3.6.b.

Air-to-Ground Intercept Link Performance as a Function of Communication Link Spread Spectrum Bandwidths.

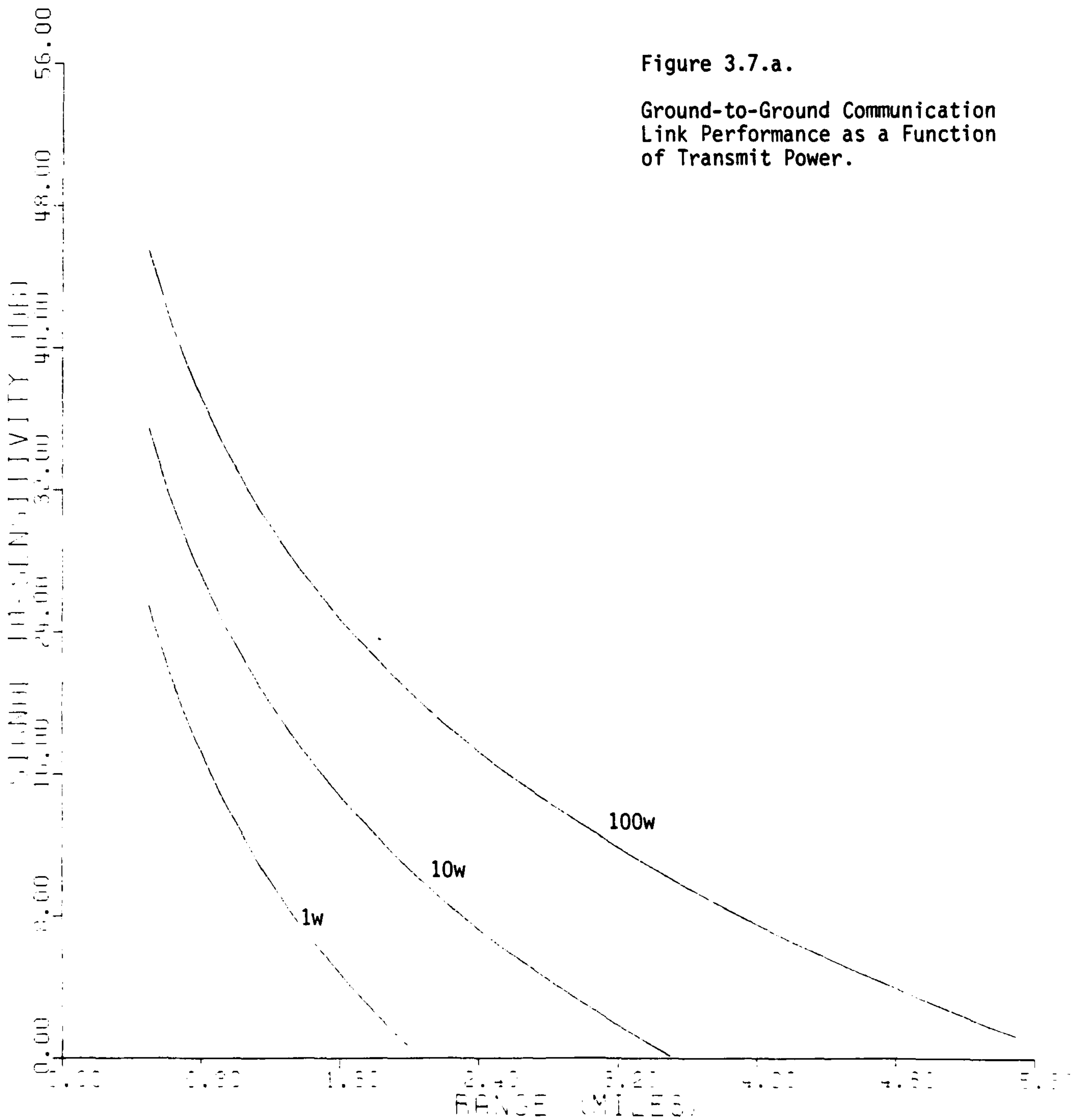


Figure 3.7.a.

Ground-to-Ground Communication Link Performance as a Function of Transmit Power.

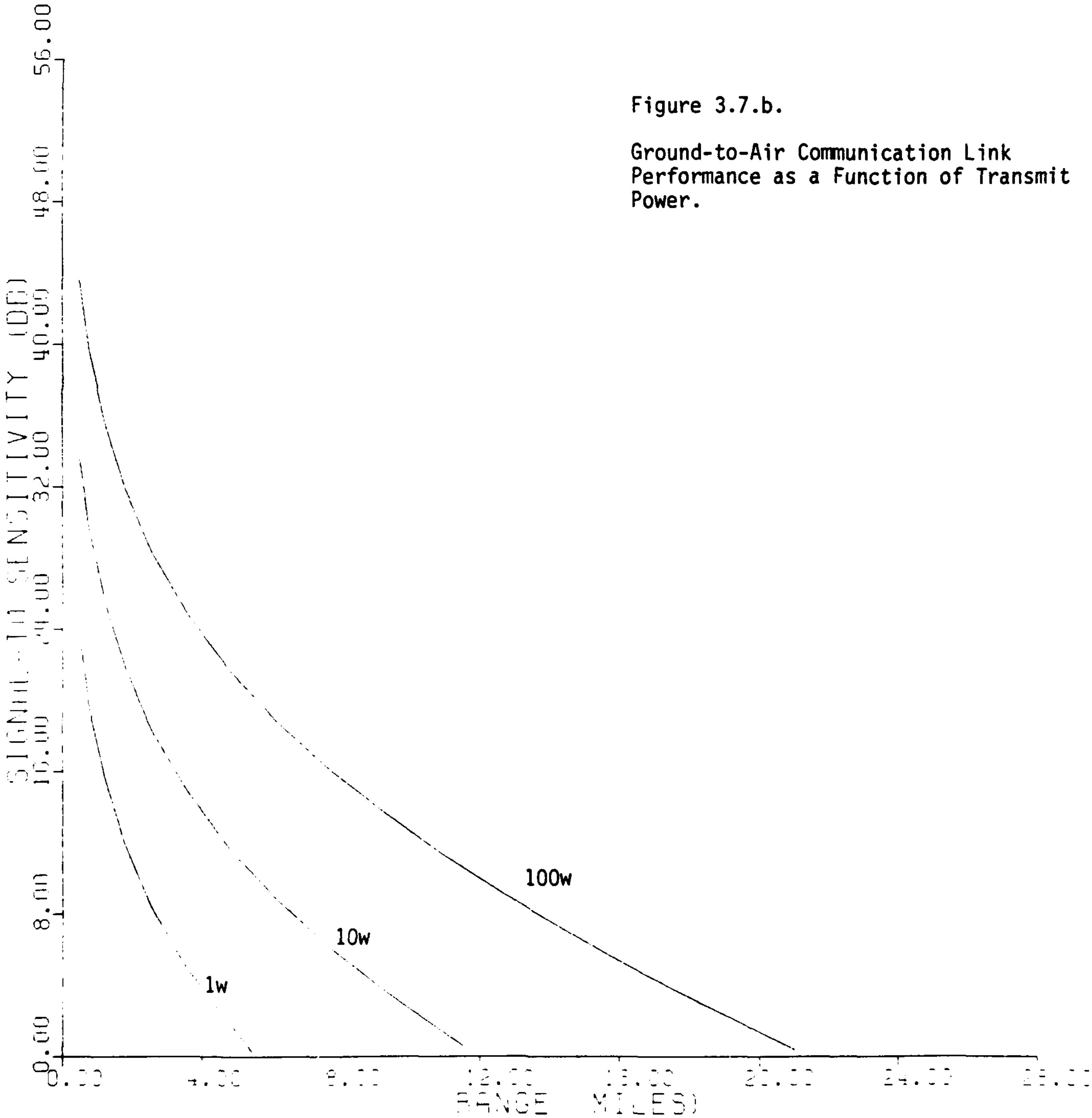


Figure 3.7.b.

Ground-to-Air Communication Link Performance as a Function of Transmit Power.

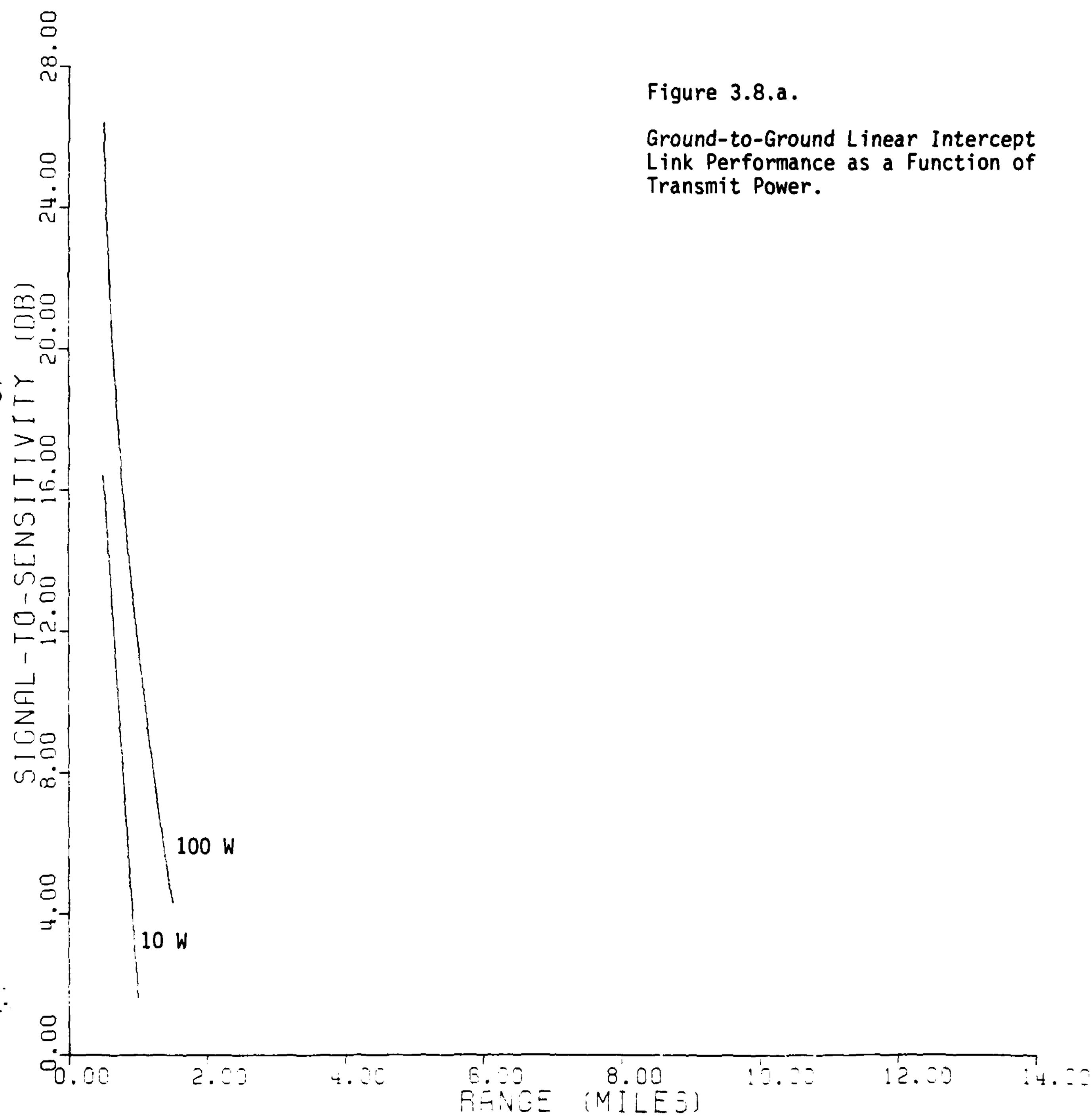


Figure 3.8.a.

Ground-to-Ground Linear Intercept Link Performance as a Function of Transmit Power.

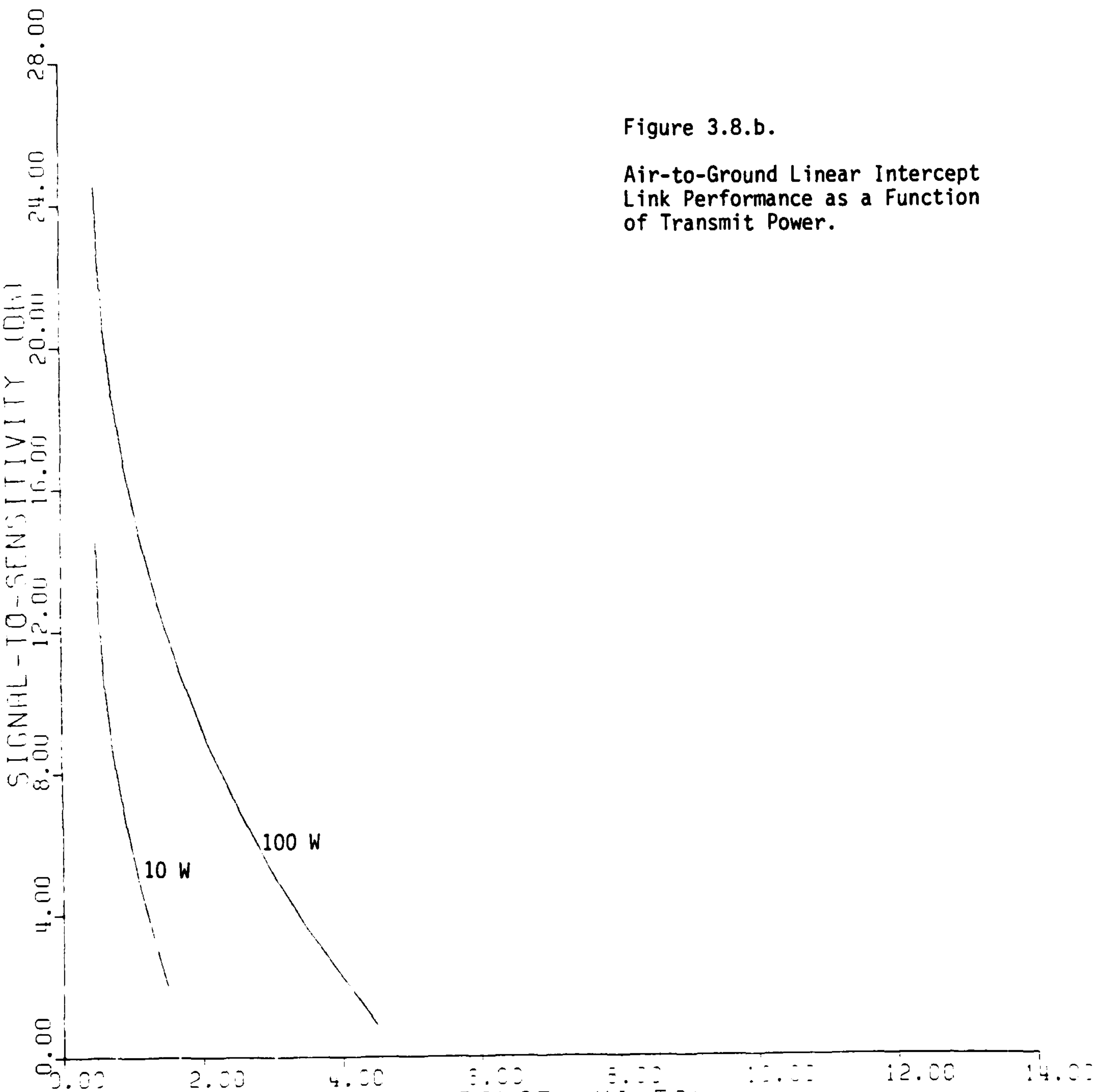


Figure 3.8.b.

Air-to-Ground Linear Intercept Link Performance as a Function of Transmit Power.

3.7.b. shows that he could use 1 watt transmit power and an airborne relay could be up to 5.5 miles distance from his position. The airborne relay could, also using Figure 3.7.b., retransmit the message to the intended receiver up to 5 miles away using only 1 watt of power. Note that Figures 3.8.a. and 3.8.b. do not have curves for 1 watt transmit power. This is because they are both unable to intercept the 100 MHz bandwidth DSE communication link at distances greater than a half-mile when its transmit power is only 1 watt. The implications of this are twofold in that it shows that power should be lowered to the minimum output required to get the message through and, of even greater importance, is the suggestion that relaying the message through an airborne station in a networking arrangement could reduce the probability of intercept and the required transmit power. It must be noted that several assumptions were made to produce this scenario but the implications of it should not be adversely affected by them. (The 25 variables used to produce Figures 3.7. and 3.8 may be found in Appendix B.) Care must be taken, however, to not draw premature conclusions from the preceeding data as only linear intercept receivers were used. Tables 3.3 a . and b. show that the link is not totally immune to intercept if the adversary is using non-linear intercept receivers. Table 3.3 a examines the performance of ground-based non-linear intercept receivers and Table 3.3 b examines the performance of airborne non-linear intercept receivers. The grim conclusion which may be drawn is that the 1 watt transmission may be intercepted out to a range of two or three miles depending on the type non-linear receiver being used for intercept.

3.1.2.4 GROUND CONSTANTS

The ground constants considered in this investigation included surface refractivity coefficient, surface conductivity, surface permittivity and the terrain radiogeology. Two of the four parameters, refractivity and radiogeology, showed nominal effects on system performance. As the system has no control over these ground constants, only a cursory analysis was done on them. Figure 3.9* shows a difference in the Ground-to-Air communication path length of about 25% over the surface refractivity range of 250 to 400 N-units.

* Tabular Data for this graph is available in Appendix B.

```
TRANSMITTER ANTENNA HEIGHT =    10.00 FT
TRANSMITTER ERP =      1.00 Watts
COMMUNICATION RECEIVER LOSS =     2.00 dB
COMMUNICATION RECEIVER ANTENNA GAIN IN THE DIRECTION OF THE TRANSMITTER =     3.00
COMMUNICATION RECEIVER ANTENNA HEIGHT =    10.00 FT
INTERCEPT RECEIVER ANTENNA HEIGHT =    60.00 FT
SNR REQUIRED AT THE COMMUNICATION RECEIVER INPUT =    13.00
QNR REQUIRED AT THE INTERCEPT RECEIVER INPUT =    10.00
ANTENNA POLARIZATION IS V
FREQUENCY = 300.00 MHz
TRANSMITTER ANTENNA GAIN IN THE DIRECTION OF THE COMMUNICATION LINK RECEIVER =     3.00
TRANSMITTER ANTENNA GAIN IN THE DIRECTION OF THE INTERCEPT RECEIVER ANTENNA =     1.00
INTERCEPT RECEIVER ANTENNA GAIN IN THE DIRECTION OF THE TRANSMITTER ANTENNA =     6.00
INTERCEPT RECEIVER TIME-BANDWIDTH PRODUCT = 1000.00
TRANSMISSION LINE LOSSES =     0.50 dB
CONDUCTIVITY =     0.02 mho/m
PERMITTIVITY =    25.00
INTERCEPT RECEIVER NOISE FIGURE =     6.00 dB
COMMUNICATION RECEIVER RESOLUTION BANDWIDTH = 25000.00 Hz
SPREAD SPECTRUM BANDWIDTH =  100.00 MHz
INTERCEPT RECEIVER RESOLUTION BANDWIDTH = 25000.00 Hz
INTERCEPT RECEIVER LOSS =     2.00 MHz
COMMUNICATION RECEIVER NOISE FIGURE =    10.00 dB
SURFACE REFRACTIVITY COEFFICIENT =  300.00
TERRAIN PARAMETER DELTA =  200.00


INTERCEPT RECEIVER DATA HAS BEEN CHOSEN


DUE TO THE REQUIRED SNR OF    10.00 dB AT THE RECEIVER INPUT
A RECEIVER SENSITIVITY OF  -81.01 dBm IS NEEDED


*****  INTERCEPT  TXPWR = 1 WATT  *****

R-FOURTH PROPAGATION
```

S I G N A L -- T O -- S E N S I T I V I T Y   R A T I O

A T   T H E   P O I N T   O F   D E T E C T I O N

Distance (miles)	AT THE INTERCEPT RECEIVER (db)	Total Power Radiometer (dB)	Dicke Radiometer (dB)	Single Channel "Delay" Correlator (dB)	Dual Channel Correlator (dB)
0.50	6.42	32.94	29.51	32.52	35.95
1.00	-8.39	12.12	6.62	9.63	15.13
1.50	-15.69				1.41

Table 3.3a Ground-Based Non-Linear Intercept Receiver Performance Against 1 watt signal.

```
TRANSMITTER ANTENNA HEIGHT =   10.00 FT
TRANSMITTER ERP =     1.00 Watts
COMMUNICATION RECEIVER LOSS =     2.00 dB
COMMUNICATION RECEIVER ANTENNA GAIN IN THE DIRECTION OF THE TRANSMITTER =     3.00
COMMUNICATION RECEIVER ANTENNA HEIGHT =    10.00 FT
INTERCEPT RECEIVER ANTENNA HEIGHT =    60.00 FT
SNR REQUIRED AT THE COMMUNICATION RECEIVER INPUT =    13.00
QNR REQUIRED AT THE INTERCEPT RECEIVER INPUT =    10.00
ANTENNA POLARIZATION IS V
FREQUENCY = 300.00 MHz
TRANSMITTER ANTENNA GAIN IN THE DIRECTION OF THE COMMUNICATION LINK RECEIVER =     3.00
TRANSMITTER ANTENNA GAIN IN THE DIRECTION OF THE INTERCEPT RECEIVER ANTENNA =    1.00
INTERCEPT RECEIVER ANTENNA GAIN IN THE DIRECTION OF THE TRANSMITTER ANTENNA =    6.00
INTERCEPT RECEIVER TIME-BANDWIDTH PRODUCT = 1000.00
TRANSMISSION LINE LOSSES =     0.50 dB
CONDUCTIVITY =     0.02 mho/m
PERMITTIVITY =    25.00
INTERCEPT RECEIVER NOISE FIGURE =     6.00 dB
COMMUNICATION RECEIVER RESOLUTION BANDWIDTH = 25000.00 Hz
SPREAD SPECTRUM BANDWIDTH =  100.00 MHz
INTERCEPT RECEIVER RESOLUTION BANDWIDTH = 25000.00 Hz
INTERCEPT RECEIVER LOSS =     2.00 MHz
COMMUNICATION RECEIVER NOISE FIGURE =    10.00 dB
SURFACE REFRACTIVITY COEFFICIENT =  300.00
TERRAIN PARAMETER DELTA =  200.00


INTERCEPT RECEIVER DATA HAS BEEN CHOSEN


DUE TO THE REQUIRED SNR OF   10.00 dB AT THE RECEIVER INPUT
A RECEIVER SENSITIVITY OF  -81.01 dBm IS NEEDED


*****  INTERCEPT  TXPWR = 1 WATT  *****

R-SQUARED PROPAGATION
```

S I G N A L -- T O -- S E N S I T I V I T Y   R A T I O

A T   T H E   P O I N T   O F   D E T E C T I O N

Distance (miles)	AT THE INTERCEPT RECEIVER (db)	Total Power Radiometer (dB)	Dicke Radiometer (dB)	Single Channel "Delay" Correlator (dB)	Dual Channel Correlator (dB)
0.50	4.53	30.82	27.20	30.21	33.83
1.00	-4.25	19.06	14.09	17.10	22.07
1.50	-8.03	12.75	7.28	10.29	15.76
2.00	-10.79	7.76	2.06	5.07	10.77
2.50	-12.98	3.63		0.82	6.64
3.00	-14.82	0.09			3.10

Table 3.3b Airborne Non-Linear Intercept Receiver Performance Against a 1 watt signal.

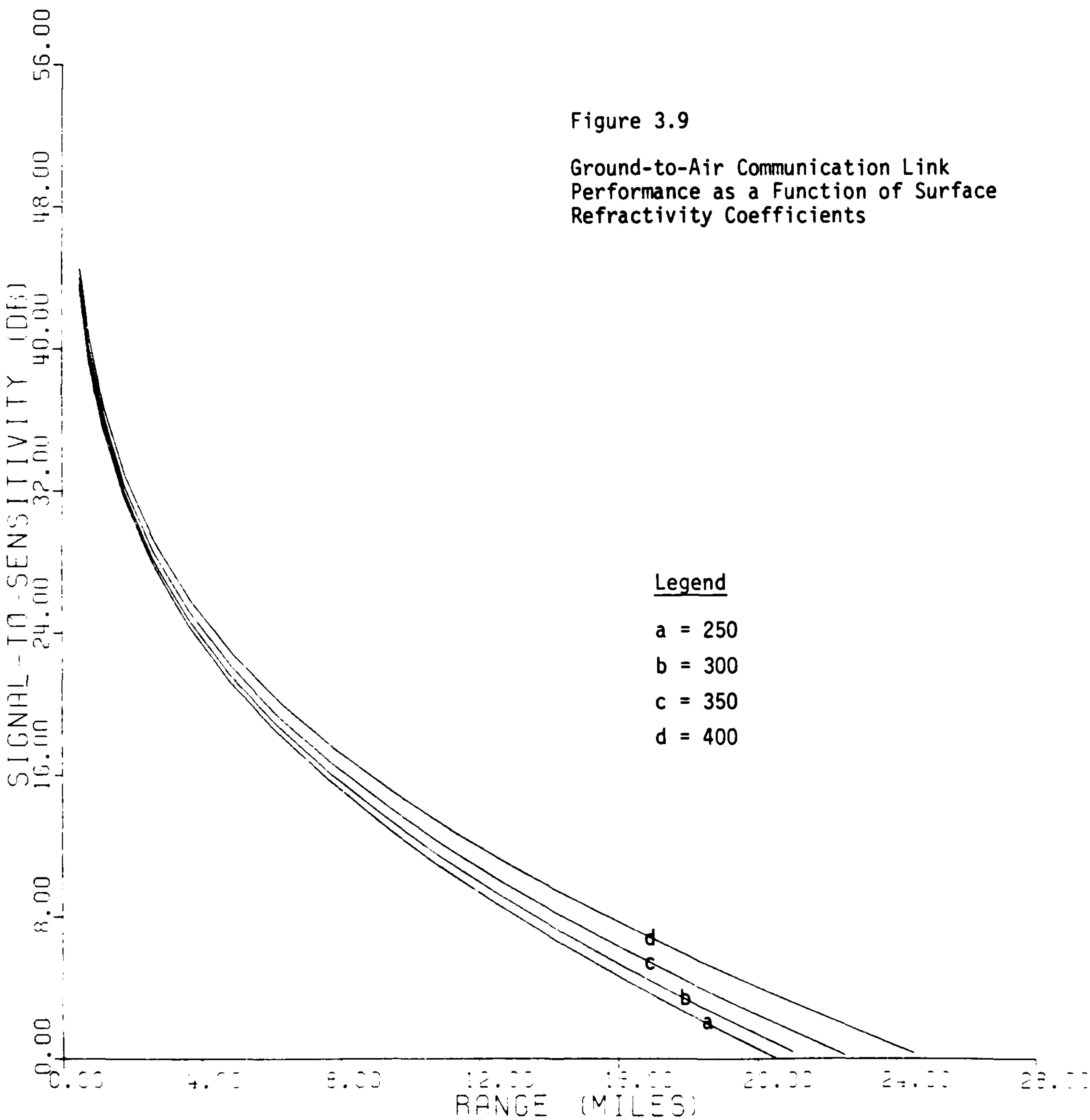


Figure 3.9

Ground-to-Air Communication Link Performance as a Function of Surface Refractivity Coefficients

<u>Legend</u>

a = 250

b = 300

c = 350

d = 400

The Terrain Radiogeology, likewise, will cause a nominal change in the communication path as evidenced in Figure 3.10* in which the radiogeology is varied from 100 to 400 on a ground-to-ground communication link.

3.1.2.5 PROPAGATION MODES

Throughout this investigation three modes of propagation have been assumed: Ground-to-Ground, Ground-to-Air, and Air-to-Air. As a convention, tabular data representing these three modes is listed under the headings R-Fourth, R-Squared, and Free-Space, respectively. In ground-to-ground propagation the attenuation is due to free space and excess losses and the signal density is understood to spread at a rate of $1/R^4$ where R is the distance from the transmitting antenna. In ground-to-air (and likewise, in air-to-ground) propagation the attenuation is also due to free space and excess losses but the density spreads at a rate of $1/R^2$. In the free space field there are no excess losses, therefore, the attenuation in air-to-air communications (at sufficient altitudes) is due to free space losses and $1/R^2$ density spreading. There is no clear distinction between the actual propagation modes; nevertheless, for analytical purposes it has been assumed that these conventions are a valid representation which can be used.

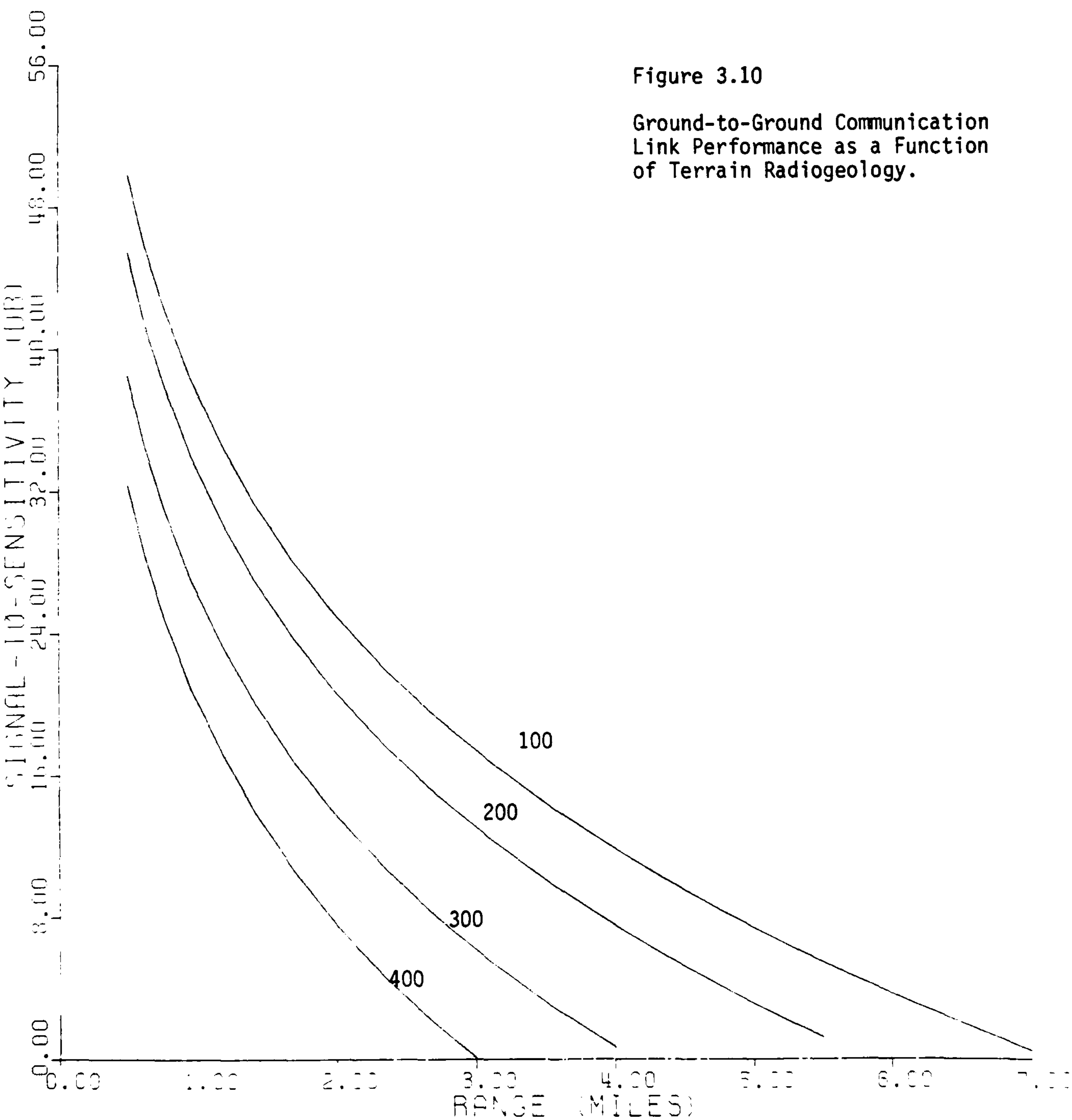


Figure 3.10

Ground-to-Ground Communication Link Performance as a Function of Terrain Radiogeology.

3.1.3 ISSUES CRITICAL TO DESIGN AND USE OF COMMUNICATION AND SIGINT SYSTEMS

3.1.3.1 POWER CONTROL AND NOISE LEVEL PLANNING

The planning of a link in terms of power and noise level is best done by means of a level diagram[10] between transmitter and receiver. In addition to those parameters in paragraph 3.1.2 above, an overall signal-to-noise ratio improvement is also possible through the use of wideband modulation methods, which permit a trade between transmitted bandwidth and signal power. Summarizing the systems planning procedure for noise performance, it may be seen from the level diagram in Figure 3.11 that it is best to start at the right from the S/N ratio required by the user and express all noise performance factors of the subsystems in decibels (dB) of power ratios (where $dB=10 \log_{10}\frac{\text{power out}}{\text{power in}}$). By adding noise improvement or subtracting loss it is thus possible to arrive at the needed transmitter power for a given connectivity distance.

3.1.3.2. MODULATION FORMATS

Most real communication channels have very poor response in the lower frequency ranges and hence are considered to be bandpass channels. To transmit digital data over bandpass channels, the information bits are transferred to a carrier frequency for transfer over the channel. Digital information can be impressed upon a carrier in many different ways, each of which deterministically modifies the phase, amplitude, or frequency of the carrier wave in a relatively simple manner. There is a price to pay for this simplicity and it can be measured in required bandwidth and/or required power compared to more complex techniques. When bandwidth is not a major consideration, digital modulation schemes perform well with a minimal amount of hardware and an inate degree of immunity to channel perturbations.

The function of a receiver in a binary communication system is to distinguish between two or more transmitted signals in the presence of the ambient noise background. Performance measurement is done by calculating the probability of error within the transmitter-receiver link and the receiver is said to be of optimum design if it yields the minimum probability of error. The receiver makes errors in the decoding process due primarily to the noise present at its input.

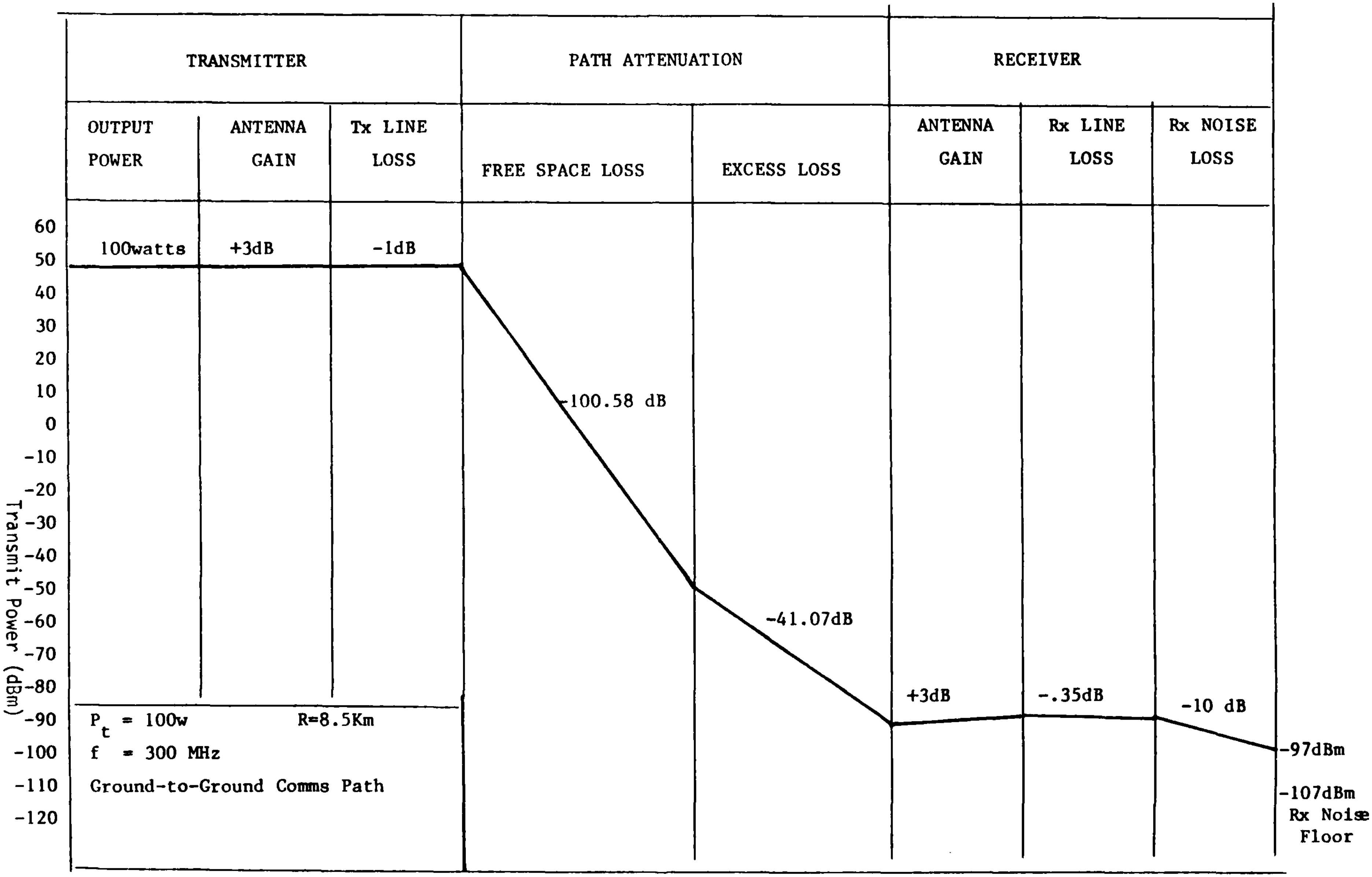


Figure 3.11 Channel Power Level Diagram

The error probability will depend on several parameters: the signal power at the receiver input, the noise power spectral density at the receiver input, the data rate, and receiver parameters (such as filter transfer function and threshold) determined by the modulation format chosen.

By holding all but two variables constant one can make useful comparisons of the digital modulation techniques, based on the function of one variable in relation to the other, to determine the one technique best suited for a particular situation. Optimization over two or more variables could provide the user with the best modulation technique for his application.

These general choices of situations are:

- Power requirements
- Immunity to noise and channel impairments
  (i.e. nonlinearities, jitter, fading, frequency offset)
- Equipment simplicity
- Data rate
- Probability of error
- Bandwidth

Figure 3.12 gives a typical plot of the probability of error versus SNR at the receiver input.[11] In a later effort an analysis of the maximum intercept range should be provided as a function of the modulation scheme chosen.

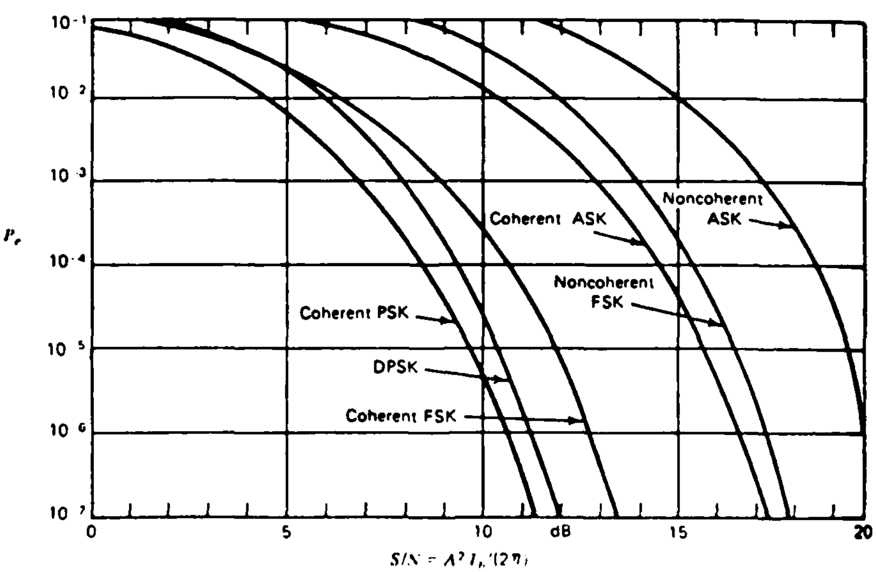


Figure 3.12. Digital Carrier Modulation Schemes

3.1.3.3. ANTENNA DIRECTIVITY AND PATTERN

A widespread misconception about antennas in radio frequency communication systems is that maximum antenna height provides maximum connectivity range. For a given frequency this is true up to a certain height above which gaps occur between the lobes of the antenna pattern (See Figure 3.13). These lobes are three dimensional contours of equal field strength between which interference patterns dominate causing destructive phase reversals. It has been proven through analyses and application[12] that the range of gapless coverage (connectivity) may actually be greatly increased in many cases by lowering the receiver antenna height. When one is working with frequencies in the VHF and lower UHF ranges over moderate distances the error in assuming that gapless coverage increases with antenna height is often made by communication system operators.

3.1.3.4 SENSITIVITY ISSUES

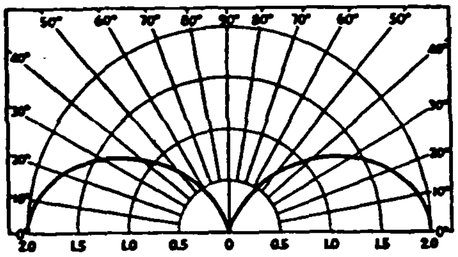
Controlling communication link and network parameters requires a thorough understanding of practical trade-offs which must be made within the system. A key issue to consider is the relationship between receiver noise figure and sensitivity.

The sensitivity of a receiver is a dependent parameter that must be defined with knowledge of the system bandwidth and the required SNR at the receiver input. Practical system sensitivities are listed in Table 3.4.

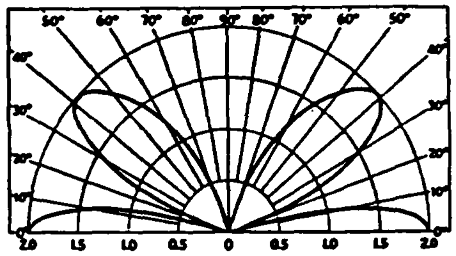
BANDWIDTH	SENSITIVITY (dBm)
100 KHz	-104
1 MHz	-94
5 MHz	-87
10 MHz	-84
30 MHz	-79
100 MHz	-74

Table 3.4 Sensitivities of a 20 dB Noise Figure Receiver at 0 dB Signal-to-Noise Ratio

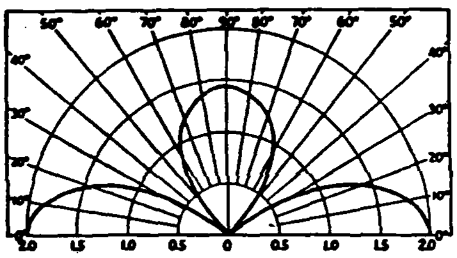
Factors by which the free-space radiation pattern of a half-wave vertical antenna should be multiplied to include the effect of reflection from perfectly conducting ground. These factors affect only the vertical angle of radiation (wave angle).



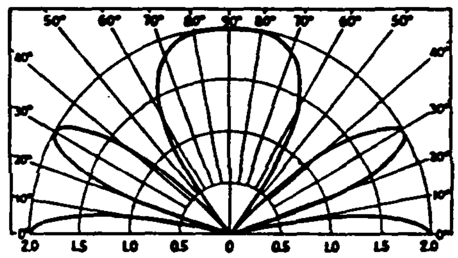
Vertical dipole antenna with center 1/4 wavelength high.



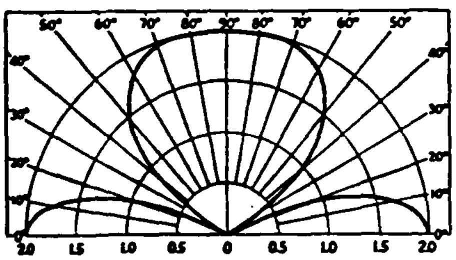
Vertical dipole antenna with center 3/4 wavelength high.



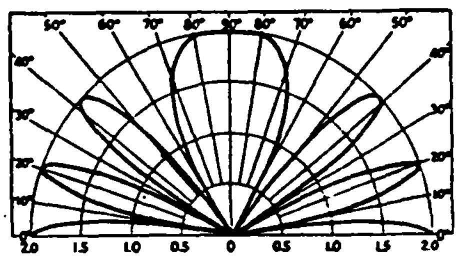
Vertical dipole antenna with center 3/8 wavelength high.



Vertical dipole antenna with center 1 wavelength high.



Vertical dipole antenna with center 1/2 wavelength high.



Vertical dipole antenna with center 1-1/2 wavelengths high.

Figure 3.13 Vertical Angles of Radiation for a Half-Wave Vertical Antenna (9)

Noise places special requirements on receiver sensitivity. Though noise sources are numerous, the primary source of it is movement of current through resistive networks which causes "thermal" noise. The thermal noise power is a function of the system bandwidth, resistance, and operating temperature. The formula for noise power is

$$P = K\,T\,B$$

where

P is defined as Thermal Noise Power in watts

K is defined as Boltzmann's Constant ($1.38 \times 10^{-23} \ \frac{\text{watt-sec}}{°K}$)

T is defined as Room Temperature (290°K)

B is defined as Receiver Bandwidth in Hertz

For Example:

For a 1 Hz bandwidth, 290 degrees Kelvin and 50 ohm system the thermal noise Power, $P = \dfrac{1.38 \times 10^{-23} \times 290 \times 1}{1 \times 10^{-3}} = 4.002 \times 10^{-18}$ milliwatts

$= -174$ dBm

It is important to note that the average distribution is constant across the VHF-UHF communication frequency range thus requiring no adjustment due to system frequency of operation. It is generally accepted that the thermal noise power is dependent on the receiver bandwidth and effective temperature. In practical systems the ambient temperature is used and the noise power is considered a function of the receiver input bandwidth.

Users rate circuit noise performance in terms of the noise figure (NF). Noise figure is noise in dB added to the received signal due to the reciever design. It is strictly a function of the receiver hardware design and is not considered an adaptive parameter for link and network purposes.

In determining receiver sensitivity four factors come into play: the thermal noise, the receiver noise figure, the bandwidth at the receiver input and the required system SNR.

$$\text{Sensitivity} = -174 \text{ dBm} + NF_{dB} + (10 \log_{10} BW_{(Hz)})_{dB} + SNR_{dB}$$

where,

-174 dBm is the best theoretical performance that could be obtained in a 50 ohm system at room temperature with no other degrading factors.

NF is the degraded sensitivity due to receiver noise.

$10 \log_{10}$ BW is the change in noise power due to change in bandwidth. The wider the BW, the greater the noise power(the higher the noise floor).

SNR is the required signal-to-noise ratio due to other system requirements such as the bit error rate (BER).

For example:

Assuming a receiver with a 1 MHz BW and 20 dB Noise Figure with a required output SNR of 10 dB, the equations for sensitivity can be expressed as

$$S = -174_{dBm} + 20_{dB} + 10 \log (1 \times 10^6)_{dB} + 10_{dB}$$

$$= -174_{dBm} + 20_{dB} + 60_{dB} + 10_{dB}$$

$$= -84_{dBm}$$

Note that the lower the acceptable SNR, the better the sensitivity must be.

If the SNR could be lowered to 0 dB, where the signal power would equal the noise power, the sensitivity required by a conventional receiver would be:

$$S = -174_{dBm} + 20_{dB} + 60_{dB} + 0_{dB} = -94_{dBm}$$

If the bandwidth were reduced to 100 KHz while retaining the same input signal level (-94dBm), the output SNR could be increased:

$$-94_{dBm} = -174_{dBm} + 20_{dB} + (10 \text{ Log}(10^5))_{dB} + \text{SNR}$$

$$\text{SNR} = -94_{dBm} + 174_{dBm} - 20_{dBm} - 50_{dB} = 10_{dB}$$

3.2 AN ANALYSIS OF THE POTENTIAL FOR FREQUENCY HOPPING

The maximum intercept range may be limited by hopping pseudorandomly in frequency over the operational communication frequency spectrum. This analysis compares the LPI achieved by hopping and non-hopping spread spectrum radios. It begins with assessments of the effectiveness of linear and non-linear intercept receiver operation against non-agile DSE spread spectrum communication links. It concludes with an analysis of the effects of pseudorandomly controlled frequency agility on intercept receiver performance.

3.2.1 LINEAR RECEIVER OPERATION AGAINST A DIRECT SEQUENCE ENCODED LINK

A Direct Sequence Encoded (DSE) spread spectrum waveform spreads the transmitted power, P_t, over the chipping bandwidth, W_{ss}, such that the average signal power spectral density, S_{APSD}, is approximately P_t/W_{ss} watts per hertz.

A linear, Fourier intercept receiver such as a conventional scanning superheterodyne receiver, compressive receiver, or digitally tuned receiver having a frequency resolution of Δf hertz will receive the following approximate average signal power in a single receiver resolution cell:

$$S_{SRC} = \frac{P_t \; G_{tr} \; G_{rt} \; K\Delta f}{\left(\frac{4\pi R}{\lambda}\right)^2 L_r \; R^{a-2} \; W_{ss}}$$

$$= (10 \log P_t)_{dBm} + G_{tr(dB)} + G_{rt(dB)} + (10 \log \Delta f)_{dB} + (10 \log K)_{dB} - FSL_{(dB)}$$

$$- L_{r(dB)} - [(a-2)\ (10 \log R)]_{dB} - (10 \log W_{ss})_{dB}$$

where

Δf is defined as a resolution cell bandwidth

W_{ss} is defined as the spread spectrum bandwidth(chipping rate)

S_{SRC} is defined as the approximate average signal

power in a single receiver resolution cell.

The average thermal noise power spectral density at the receiver, N_{APSD}, is given by

$$N_{APSD} = \frac{KTBN_{fo}}{W_{ss}} \text{ (watts/hertz)}$$

$$= (10 \log KTB)_{dB} + (N_{fo})_{dB} - (10 \log W_{ss})_{dB}$$

Likewise, a linear Fourier intercept receiver having a frequency resolution of Δf hertz will receive the following approximate average thermal noise power N_{SRC} in a single receiver resolution cell:

$$N_{SRC} = \frac{KTBN_{fo} \ \Delta f}{W_{ss}} = \frac{KTW_{ss} \ N_{fo} \ \Delta f}{W_{ss}} = KTN_{fo} \ \Delta f$$

$$= (10 \log (KT))_{dB} + (N_{fo})_{dB} + (10 \log \Delta f)_{dB}$$

where

K	is defined as Boltzmann's constant
T	is defined as absolute temperature
N_{fo}	is defined as the noise figure of the receiver
B	is defined as the receiver noise Bandwidth=W_{ss}
W_{ss}	is defined as the spread spectrum bandwidth(chipping rate)

The Average Signal Power Spectral Density to Average Noise Power Spectral Density Ratio, (SNR) Δ f in a resolution bin at the receiver is given by

$$(SNR)_{\Delta f} = \frac{S_{SRC}}{N_{SRC}} = \frac{P_t \ G_{tr} \ G_{rt} \ K\Delta f}{\left(\frac{4\pi R}{\lambda}\right)^2 L_r \ R^{a-2} \ W_{ss}} \quad \frac{1}{KTN_{fo} \ \Delta f}$$

$$= \frac{P_t \ G_{tr} \ G_{rt} \ K}{\left(\frac{4\pi R}{\lambda}\right)^2 L_r \ R^{a-2} \ W_{ss} \ KTN_{fo}}$$

$$= \ (10 \log P_t) + G_{tr(dB)} + G_{rt(dB)} + (K)_{dB}$$

$$- (FSL)_{dBm} - (L_r)_{dB} - [(a-2)(10 \log R)]_{dB} - (10 \log W_{ss})_{dB}$$

$$- (10 \log KT)_{dB} - (N_{fo})_{dB}$$

The resulting performance of the linear intercept receiver is as if all the transmitted power is being intercepted requiring a receiver analysis bandwidth or resolution bandwidth equal to the DSE bandwidth of W_{ss} hertz.

A useful indicator of a communication system's performance is the effective range of communication. Using some appropriate criterion (speech intelligibility, symbol error rate, etc) a minimum acceptable value for this power ratio in a linear receiver can be specified.

Corresponding to any value for the appropriate criterion a minimum SNR can be chosen. For the minimum required SNR to produce the appropriate criterion value there is associated a maximum value for range R_{tr}. This is called the effective range of communications; thus

$$R_{tr} > R_{tr,max} \Rightarrow (SNR) < (SNR)_{min} \quad \text{(insufficient connectivity)}$$

$$R_{tr} < R_{tr,max} \Rightarrow (SNR) > (SNR)_{min} \quad \text{(sufficient connectivity)}$$

$$R^{a-2}_{tr,max} = \frac{P_t \ G_{tr} \ G_{rt}}{\left(\frac{4\pi}{\lambda}\right)^2 L_r \ N_{oi} \ W_{ss} \ (SNR)_{oi}}$$

Clearly, from R_{tr} max above, against linear Fourier intercept receivers, the best tool a communication link can use is to lower the intercepter's received SNR by any combination of means possible. It has been shown in section 3.1 above that many parameters may be adjusted by the communicators to accomplish this.

3.2.2 NON-LINEAR RECEIVER OPERATION AGAINST A DIRECT SEQUENCE ENCODED LINK

As it has been shown that the performance of a linear Fourier intercept receiver such as a scanning superheterodyne receiver, compressive receiver, or a digitally tuned receiver having a frequency resolution of Δf is adversely affected by small changes in several readily adaptive parameters, it is expected that the intercepter will enhance his capability by choosing non-linear intercept receivers such as radiometers, correlators, and frequency doublers. Analysis of the performance of these non-linear intercept receiver techniques follows.

For generality, assume that the intercept receiver is non-linear having an output Signal-to-Noise Ratio $(SNR)_o$ given by

$$(SNR)_o = \frac{\beta \left(SNR_{in}\right)^2 T_I W_{ss}}{1 + \frac{\beta}{\alpha}\left(SNR_{in}\right)}$$

where,

T_I is defined as the integration time of the non-linear receiver

W_{ss} is defined as the intercept receiver RF bandwidth (assumed equal to the total DSE waveform bandwidth)

α and β are defined as constants depending on type detection receiver chosen (See Table 3.5)

$\left(SNR_{in}\right)$ is defined as the input signal-to-noise ratio in a resolution bin at the intercept receiver where the resolution bin is considered equal to the total DSE waveform bandwidth, W_{ss}.

General Formula

$$SNR_O = \frac{\beta\,(SNR_{IN})^2\; T_I\; W_{ss}}{1 + \frac{\beta}{\alpha}\,(SNR_{IN})}$$

NON-LINEAR RECEIVER TYPE	α	β
Total Power Radiometer	0.5	1.0
Dual Channel Correlator	1.0	2.0
Single Channel "Delay" Correlator	0.5	0.5
Dicke Radiometer	0.25	0.25

Table 3.5 Values of α and β for Several Non-Linear Intercept Receivers

A non-linear intercept receiver such as a radiometer, wideband channelized correlator, or frequency doubler having a frequency resolution of W_{ss} hertz (equal to the total spectrum in which the DSE waveform can be found) will receive the following approximate average signal power in the receiver:

$$S_{W_{ss}} = \frac{P_t\; G_{tr}\; G_{rt}\; W_{ss}}{(4\pi/\lambda)^2\; L_r\; R^a\; W_{ss}} = \frac{P_t\; G_{tr}\; G_{rt}}{(4\pi/\lambda)^2\; L_r\; R^a}$$

where

W_{ss} is defined as the frequency resolution of the receiver in the numerator, which is assumed equal to the spread spectrum bandwidth in the denominator.

$S_{W_{ss}}$ is defined as the approximate average signal power in the non-linear receiver bandwidth of W_{ss}.

The average thermal noise power spectral density at the receiver, N_{APSD}, is the same as that for the linear receiver, again given by

$$N_{APSD} = \frac{K\ T\ B\ N_{f_0}}{W_{ss}} \qquad (\text{watts}/\text{hertz})$$

Opposed to the linear Fourier intercept receiver which has a frequency resolution of Δf hertz, the non-linear intercept receiver is assumed to have a resolution of W_{ss} equal to the spread spectrum bandwidth. As such, the non-linear receiver will receive the following approximate average thermal noise power, $N_{W_{ss}}$:

$$N_{W_{ss}} = \frac{K\ T\ B\ N_{f_0}\ W_{ss}}{W_{ss}} = \frac{K\ T\ W_{ss}\ N_{f_0}\ W_{ss}}{W_{ss}}$$

$$= K T\ N_{f_0}\ W_{ss}$$

The average Signal Power Spectral Density to Average Noise Power Spectral Density Ratio $(SNR)_{W_{ss}}$ at the receiver is therefore

$$SNR_{W_{ss}} = \frac{S_{W_{ss}}}{N_{W_{ss}}} = \frac{P_t\ G_{tr}\ G_{rt}}{(4\pi/\lambda)^2\ L_r\ R^4\ K\ T\ N_{f_0}\ W_{ss}}$$

Comparison of $(SNR)_{W_{ss}}$ to $(SNR)_{\Delta f}$ reveals that the input signal-to-noise ratio at the receiver is equal for linear and non-linear receivers. As the radiometer, correlator, or frequency doubler is a non-linear receiver, the signal-to-noise ratio at the point of detection $(SNR)_{pod}$ rather than at the receiver input, must be computed. This is due to the fact that the $(SNR)_{pod}$ is a function of the product of integration Time T_I and spread spectrum bandwidth, W_{ss}. For generality, one can assume that the intercept receiver has a SNR at the point of wideband signal detection of

$$SNR_{Pod} = \frac{\beta\ (SNR_{IN})^2\ T_I\ W_{ss}}{1 + \frac{\beta}{\alpha}\ (SNR_{IN})}$$

where

T_I is defined as the integration time of the non-linear receiver,

α and β are defined as constants depending on the type of non-linear receiver chosen.

Using the quadratic formula and some viable assumptions $(SNR)_{in}$ can be evaluated.

$$\beta T_I W_{ss} (SNR_{in})^2 - \frac{\beta}{\alpha} (SNR_{in})(SNR_{Pod}) - SNR_{Pod} = 0$$

$$\therefore \quad (SNR_{in}) = \frac{-\left(-\frac{\beta}{\alpha}(SNR_{Pod})\right) \pm \sqrt{\frac{\beta^2 (SNR_{Pod})^2}{\alpha^2} - 4(-SNR_{Pod})(\beta T_I W_{ss})}}{2 \beta T_I W_{ss}}$$

$$= \frac{SNR_{Pod}}{2 \alpha T_I W_{ss}} \pm \frac{1}{2 \alpha T_I W_{ss}} \sqrt{\beta (SNR_{Pod})^2 + 4 T_I W_{ss} \alpha^2 SNR_{Pod}}$$

$$= \frac{SNR_{Pod} \pm \sqrt{\beta (SNR_{Pod})^2 + 4 T_I W_{ss} \alpha^2 SNR_{Pod}}}{2 \alpha T_I W_{ss}}$$

$$= \frac{1 \pm \sqrt{\beta (SNR_{Pod})^2 + 4 T_I W_{ss} \alpha^2 (SNR_{Pod})}}{\frac{2 T_I W_{ss} \alpha}{SNR_{Pod}}}$$

$$SNR_{IN} = \frac{1 \pm \sqrt{1 + \dfrac{4 T_I W_{ss} \alpha^2}{\beta \, SNR_{Pod}}}}{\dfrac{2 T_I W_{ss} \alpha}{SNR_{Pod}}}$$

But only one of these two roots will give a useable $(SNR)_{in}$ value. That is:

$$SNR_{IN} = \frac{1 + \sqrt{1 + \dfrac{4 T_I W_{ss} \alpha^2}{\beta (SNR_{Pod})}}}{\dfrac{2 T_I W_{ss} \alpha}{SNR_{Pod}}}$$

From previous discussion it should be understood that

$SNR_{IN} = SNR_{W_{ss}}$ for the non-linear receivers.

Therefore, $$SNR_{IN} = \frac{P_t \, G_{ti} \, G_{it}}{(4\pi/\lambda)^2 \, L_I \, R_I^a \, K \, T \, N_{f_o} \, W_{ss}}$$

The intercept range can therefore be determined for non-linear receivers as

$$R_I = \sqrt[a]{\frac{P_t \, G_{ti} \, G_{it}}{(4\pi/\lambda)^2 \, L_I \, K \, T \, N_{f_o} \, W_{ss} \, SNR_{IN}}}$$

or in final terms

$$R_I = \sqrt[a]{\frac{2\, P_t\, G_{it}\, G_{ti}\, T_I\, \alpha}{\left[(4\pi/\lambda)^2 (SNR_{pod})(L_I)(KTN_{fo})\right]\left[1 + \frac{4\, T_I\, W_{ss}\, \alpha^2}{\beta\,(SNR_{pod})}\right]}}$$

R_I will be the maximum possible intercept range of a non-linear receiver if $(SNR)_{pod}$ is the minimum SNR with which interception of the signal may be achieved.

From R_I an analysis of the intercept range of a non-linear receiver may be conducted. Maximum intercept ranges can be plotted as functions of:

The attenuation component on the propagation path,
Power transmitted,
Transmitter antenna gain in the direction of the intercept receiver,
Intercept receiver antenna gain in the direction of the transmitter,
Integration time at the intercept receiver,
Type of non-linear intercept receiver used based on α and β values,
Signal to noise ratio at the intercept receiver's point of detection,
Intercept Receiver Loss,
Average thermal noise power spectral density at the input to the intercept receiver,

Operating frequency,
Receiver Noise factor, and
Effective temperature.

Once again, as with linear intercept receivers, against non-linear intercept receivers the best tool a link can use is to lower the received SNR.

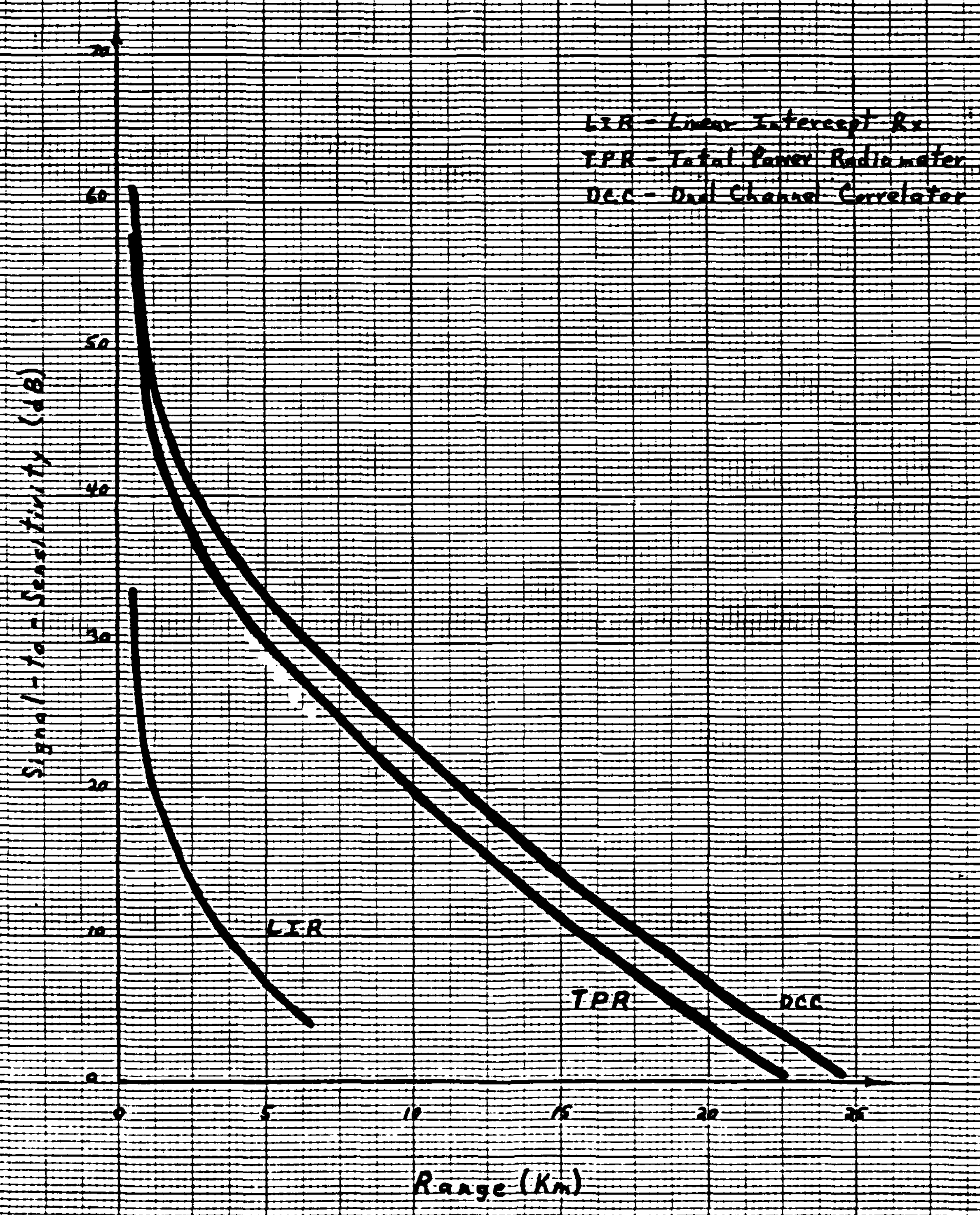
Figure 3.14 provides a comparison of the performance of a linear intercept receiver with that of the non-linear Total Power Radiometer, Squarer-Frequency Doubler, and the Dual Channel Correlator when they are used aginst the same 100 MHZ bandwidth DSE signal. Clearly the non-linear receivers outperform the linear intercept receiver. It is important to note that the non-linear receivers work even with a slightly negative input SNR.

3.2.3 THE EFFECTS OF PSEUDORANDOMLY CONTROLLED FREQUENCY AGILITY

Intercept receiver performance, as discussed in the previous two sections, is dependent on numerous other variables. For reasons previously given, linear intercept receivers were determined to be much less effective than non-linear intercept receivers against DSE spread spectrum signals. As such, use of linear receiving devices is not expected to be a viable alternative for development of spread spectrum intercept systems with today's technology. On the other hand, non-linear devices such as correlators, convolvers, radiometers, etc. are in existence today and it is expected that their capability to intercept wideband signals in the RF spectrum is at least as good as their capability in the radar ranges at higher frequencies where they have proven to be an effective approach for the past few decades.

A close look at the range equations given in the previous section reveals that the intercept range R_I is a function of the time, T_I, over which one might integrate the received spectrum.

Figure 3.14 Comparison of the Performance of Interceptors



$$R_I = a \; \frac{2 \, P_t \, G_{it} \, G_{ti} \, T_I \, \alpha}{\left(\frac{4\pi}{\lambda}\right)^2 \; (SNR_{pod}) \; (L_I) \; (KTN_{fo}) \quad 1 + \frac{4 \, T_I \, W_{ss} \, \alpha^2}{B \, (SNR_{pod})}}$$

Decreasing the integration time, T_I, below the time over which the background noise can be expected to reasonably stay constant, will, in turn, decrease the range over which a non-linear intercept receiver can operate.

3.3 PROPAGATION MODELING

3.3.1 THE LONGLEY-RICE IRREGULAR TERRAIN MODEL

The Longley-Rice Irregular Terrain Model was developed as a computer method for use in calculating radio transmission loss over irregular terrain. This method may be used to calculate transmission loss for very specific paths and terrain characteristics but proves most useful in those cases where only a general terrain profile is available. The predictions obtained from Longley-Rice have been confirmed using field data collected for a variety of frequencies, antenna heights, distances, and terrain contours. Transmission loss is calculated as a function of distance.

This model has several characteristics which make it useful in predicting radio transmission loss. It is quite adaptable and can be used with a broad frequency range (20 - 40,000 MHz) a large assortment of antenna heights (0.5 to 3,000 m), and over a vast distance range (1 to 2,000 km). Terrain contours include all types from water or very smooth plains to extremely rugged mountains. Results obtained from this method are supported by empirical data collected worldwide. The method also considers such factors as surface refractivity, ground conductivity, ground permittivity, and others, weighting each as appropriate for the given distance, frequency, antenna heights, and terrain. [13]

However, there are certain peculiarities of the Longley-Rice method which result in less than optimal predictions for wide-band spread spectrum radio communications. It was developed primarily as a tool to be applied to narrow-band radio signals. Consequently, there are distinct inadequacies in several areas such as wide-band signal attenuation, vegetation effects, and effects resulting from spatial arrangement of receivers and time-variant multipath. [14] In the current effort, for lack of a better model, Longley-Rice was applied. Although the Longley-Rice ITM has proven effective in our research into the various radio signal propagation modes, it has become apparent that in the advent of new technology the method is becoming increasingly limited in its applicability. In conclusion, it is strongly recommended that continuing research to develop a general wide-band signal propagation model be undertaken.

3.3.2 SOFTWARE OVERVIEW

The model incorporates the Longley-Rice ITM as the basis for the computation of the excess loss figure. There are some modules which perform succeeding calculations based on this figure. Others do not use this excess loss figure. Those modules of particular significance will be described further.

Receiver sensitivity is computed for the communications receiver as well as for both linear and non-linear type intercept receivers. This sensitivity value is independent of the signal propagation mode.

Three distinct signal propagation modes are explored:

(1) Air-to-Air
(2) Air-to-Ground
(3) Ground-to-Ground

Signal-to-sensitivity ratios are computed for the communications and intercept receivers for each of these modes of propagation.

The signal-to-sensitivity ratios are computed as a function of range for both the communications and intercept receivers. The communications receiver is assumed to be linear while the intercept receiver may be linear or non-linear. Five specific types of non-linear intercept receivers are examined. These included the total power and Dicke radiometers, the single channel "delay" and dual channel correlators, as well as the squarer frequency doubler. Graphs of signal-to-sensitivity as a function of range were produced using the Versaplot - 07 graphics package which is a product of Versatec. Versaplot-07 is designed to allow the user to write graphics programs for the Versatec family of electrostatic plotters.

4.0 NETWORK ANALYSIS

4.1 INTRODUCTION

Research under this effort addresses how to control spread spectrum communication system parameters in a link and network sense to achieve an improved measure of LPI. This section addresses network parameter interaction where the issue is how to control spread spectrum links on a network-wide basis.

The communication network concept for future battlefield operations envisions multiuser, physically dispersed, dynamically connected networks which possess an inate degree of survivability. The tactical military units of the future are expected to operate as independent islands rather than along a conventional front where units traditionally stood shoulder-to-shoulder. As such, reliance on communication network survivability is tantamount to the success of this nodal plan of operations. Due to the vacillating connectivity anticipated in the battlefield communication network of the future, a dynamic control technique is essential.

A Direct Sequence Encoded (DSE) network is composed of communication links each of which is controlled by a pseudorandom code. To increase throughput in the network the pseudorandom codes used for the communication links are chosen so that they will limit mutual interference. The necessity for this arises from the fact that mutual interference gives rise to an increase in bit error rates. Adjustment of several parameters within the transceivers can provide maximum communication range with a high probability of connectivity while simultaneously providing minimum intercept range and low probability of intercept by unintended receivers. The optimized communication network using DSE spread spectrum signalling techniques, adaptive network control, and sophisticated hardware will present a formidable problem to the signals intelligence and to the electronic warfare assets of tactical adversaries on the battlefield of the 1990's.

In this study of network analysis an evaluation was made in three areas of interest:

1. Air-to-Ground Intercept (Section 4.2)
2. Ground-to-Ground Intercept (Section 4.3)
3. Air-to-Air Intercept (Section 4.4)

These three modes of propagation can be used to characterize any communication network in its entirety.

Outlining Air-to-Ground Intercept and Ground-to-Ground Intercept, we analyzed the power of the transmitted communication signal at the communication receiver, denoted S, the power of the transmitted signal received at the intercept receiver, denoted Q, the communicator's interference power from one friendly transmitter, denoted I_1, the total interference, denoted I, the interference due to the $1^{\underline{th}}$ source at the intercepter, I_1^Q, and total interference of the intercept, I^Q. For one to communicate,

$$S \geq 10\ I.$$

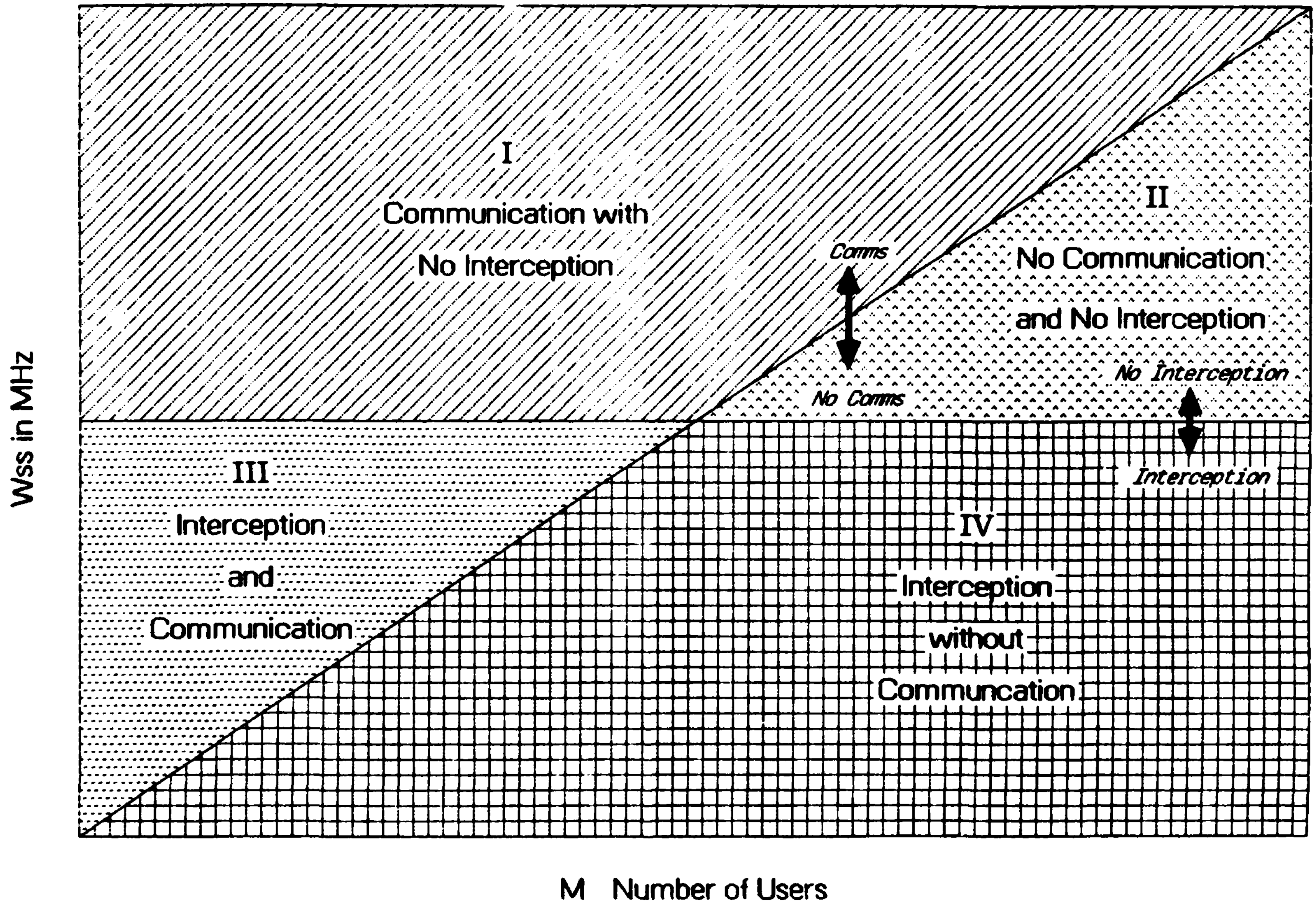
Solving this equation, we could graphically show when communication is possible. In order to intercept:

$$Q \geq 10\ [N_i + I^Q]$$

where N_i is the thermal noise. Solving for this equation we can find the area in which interception can be avoided.

A synopsis of how the curves relate and given ar[illegible] where there is "communication with no interception", "communication with intercept", "no communication with intercept", and "no communication with no intercept" are summarized graphically in Figure 4.1, generic snapshot format.

In Air-to-Ground Intercept, Section 4.3, when working with the interference at the intercepter, I^Q, we studied three separate cases. Case one is when the interceptor is standing-off and is interference limited, in Case two, the inter-


I
Communication with
No Interception
II
No Communication
and No Interception
Comms
No Comms
No Interception
Interception
III
Interception
and
Communication
IV
Interception
without
Communcation
Wss in MHz
M Number of Users

ceptor is standing-off when not interference limited, and Case three is when the interceptor is over the communication network. The assumption of Case one being interference limited was mathematically proven.

Following Section 4.2 and 4.3 will be a graph that will show the interceptor is interference limited, plus the scenario snapshots for Air-to-Ground Intercept and Ground-to-Ground Intercept respectively. Section 4.4 will be discussed briefly, with little analysis.

4.2 AIR-TO-GROUND INTERCEPT

The power of the transmitted communication signal at the communication receiver, denoted S, is given as the following expression:

$$S = \frac{P_T G_{TR} G_{RT}}{\left[\frac{(4\pi)^2 K_c}{\lambda^2}\right] R_c^4 L_c} \quad (1)$$

where

P_T =Transmitted Communication Power

G_{TR} =Transmitter Antenna Gain in the Direction of the Communication Receiver (relative to omni)

G_{RT} =Communication Receiver Antenna Gain in the Direction of the Transmitter (relative to omni)

λ =Wavelength of center frequency of the communication signal

K_c =Constant of attenuation

R_c =Communication Distance

L_c =Loss at the Communication Receiver.

From propagation curves,[16] the value of K_c is 37.4dB, in units of 1/mi.^{2}.

Define

$$\langle R_F \rangle^2 \equiv \frac{A}{\pi M} \quad (1a)$$

where R_F is the radius of friendly radio net operation

A is the area covered by the network

M is the total possible number of simultaneous transmitters

As the number of users in the network gets larger, the average range of the friendly communicator decreases.

$$\langle R_F \rangle^4 \equiv \left[\frac{A}{\pi M}\right]^2 \quad (1b)$$

Assume

$$A \cong 71 \times 71 \text{ sq. miles}$$
$$= 5026.55 \text{ sq. miles}$$

Substituting into (1_b)

$$\langle R_F \rangle^4 = \left[\frac{5026.55}{\pi M}\right]^2$$

$$= \frac{2.56 \times 10^6 \text{ mi}^2}{M^2}$$

$$\langle R_F \rangle^4 = \frac{10^{6.41}}{M^2}$$

letting

$$G_{TR} = 0\text{dB} = 1.0 \quad f = 300\text{MHz} \quad \langle R_F \rangle^4 = R_c^4$$

$$G_{RT} = 0\text{dB} = 1.0 \quad \lambda = 6.214 \times 10^{-4} \text{ statute mi.}$$

$$\left[\frac{(4\pi)^2 K_c}{\lambda^2}\right] = 10^{12.354} \,(1/\text{mi}^2)$$

$$L_c = 6\text{dB} = 10^{.6}$$

and substituting into equation (1)

$$S = \frac{(1.0)(1.0)}{10^{12.354}\,10^{6.41}\,10^{.6}} M^2 P_T$$

$$S = \left[4.33 \times 10^{-20}\right] M^2 P_T \qquad (2)$$

The power of the transmitted signal received at the intercept receiver, denoted Q, is defined as the following:

$$Q = \frac{P_T G_{TI} G_{IT} W_I}{\left[\frac{(4\pi)^2}{\lambda^2}\right] R_I^2 L_I W_{SS}} \tag{3}$$

where

G_{TI} =Transmitter Antenna Gain in the Direction of the Intercept receiver (relative to omni)

G_{IT} =Intercept Receiver Antenna Gain in the Direction of the transmitter (relative to omni)

W_I =Intercept Bandwidth

R_I =Intercept Range

L_I =Loss at intercept Receiver

W_{SS} =Spread Spectrum Bandwidth

$$Q = \frac{P_T W_I}{W_{SS}} \; \frac{G_{TI} G_{IT}}{\left[\frac{4\pi R_I}{\lambda}\right]^2 L_I} \tag{4}$$

assuming

$G_{TI} = 0\,dB = 1.0$

$G_{IT} = 6\,dB = 10^{.6}$

At an intercept range of 10 miles,

$$\left[\frac{4\pi R_I}{\lambda}\right]^2 = \left[\frac{(4\pi)(10)(3\times10^8)}{(3\times10^8)(6.214\times10^{-4})}\right]^2 \tag{5}$$

$$= 4.09\times10^{10}$$

Substituting into equation (4), and using a 3 dB intercept receiver loss

$$Q = \frac{P_T W_I}{W_{SS}}\left[\frac{(1)(10^{-6})}{(4.09\times10^{10})(10^{\cdot 3})}\right]$$

$$Q = \left[4.88\times10^{-11}\right]\frac{P_T W_I}{W_{SS}} \tag{6}$$

Next we need to look at the communicator'sinterference power from one friendly transmitter, I_ℓ, given by

$$I_\ell = \frac{P_T G_{F_\ell R} G_{RF_\ell} W_{BB}}{\left[\frac{(4\pi)^2 K_{F_\ell}}{\lambda^2}\right] R_{F_\ell}^4 L_C 2W_{SS}} \tag{7}$$

where

$G_{F_\ell R}$ = Transmitter antenna gain in the direction of the communication receiver (relative to omni)

G_{RF_ℓ} = Communication receiver gain in the direction of the friendly transmitter (relative to omni)

W_{BB} = Baseband bandwidth

K_{F_ℓ} = Constant of attenuation

R_{F_ℓ} = Friendly transmitter distance

Letting

$$G_{F_\ell R} = 0\,dB = 1.0$$

$$G_{RF_\ell} = 0\,dB = 1.0$$

$$\left[\frac{(4\pi)^2 K_{F_\ell}}{\lambda^2}\right] = 10^{12.354}$$

$$L_c = 6\,dB = 10^{.6}$$

$f = 300$ MHz

$\lambda = 6.214 \times 10^{-4}$ statute miles

and substituting into (7)

$$I_\ell = (10^{-12.954})\left(\frac{1}{R_{F_\ell}^{\,4}}\right)\left(\frac{P_T W_{BB}}{2W_{SS}}\right) \tag{8}$$

$$= [5.56 \times 10^{-14}]\left(\frac{1}{R_{F_\ell}}\right)^4\left(\frac{P_T W_{BB}}{W_{SS}}\right)$$

$$I = \sum_{\ell=1}^{L} I_\ell$$

$$= [5.56 \times 10^{-14}]\,\frac{P_T W_{BB}}{W_{SS}} \sum_{\ell=1}^{L} \frac{1}{R_{F_\ell}^{\,4}} \tag{9}$$

where

L = PM = Actual number of simultaneous users
M = Total possible number of simultaneous users
P = Probability of being on the air (User Duty Cycle)

Let

$$R_{F_\ell} = \alpha_\ell \langle R_F \rangle$$ where, α_ℓ = attenuation at range, R_F

and substituting into (9)

$$I = 5.56 \times 10^{-14} \frac{P_T W_{BB}}{W_{SS}} \left[\sum_{\ell=1}^{L} \frac{1}{\alpha_\ell^4 \langle R_F \rangle^4} \right]$$

$$= \frac{5.56 \times 10^{-14}}{2.56 \times 10^{6}} \frac{M^2 P_T W_{BB}}{W_{SS}} \left[\sum_{\ell=1}^{L} \frac{1}{\alpha_\ell^4} \right]$$

$$= 2.17 \times 10^{-20} \frac{M^2 P_T W_{BB}}{W_{SS}} \left[\sum_{\ell=1}^{L} \frac{1}{\alpha_\ell^4} \right]$$

$$I = 2.17 \times 10^{-20} \frac{P M^3 P_T W_{BB}}{W_{SS}} \left\{ \frac{1}{L} \sum_{\ell=1}^{L} \frac{1}{\alpha_\ell^4} \right\} \qquad (10)$$

If δ = minimum standoff distance and 3 $+\delta$ = maximum standoff distance then,

Assuming α_ℓ is uniform on $[\delta, 3+\delta]$

$$E\left\{\frac{1}{\alpha_\ell^4}\right\} = \frac{1}{3} \int_{\delta}^{3+\delta} \frac{1}{x^4}\, dx = \int_{\delta}^{3+\delta} x^{-4}\, dx$$

$$= \frac{1}{3} \left. \frac{x^{-3}}{(-3)} \right|_{\delta}^{3+\delta}$$

$$:= \left. \frac{x^{-3}}{9} \right|_{3+\delta}^{\delta} = \frac{1}{9\delta^3} - \frac{1}{9(3+\delta)^3}$$

$$= \frac{1}{9\delta^3} \qquad (11)$$

and substituting into (10),

$$I = 2.17 \times 10^{-20} \frac{PM^3 P_T W_{BB}}{W_{SS}} \frac{1}{9\delta_I^3} \tag{12}$$

In order to communicate, assuming that the communicator's receiver is interference limited and not thermal noise limited, (this is virtually always the case)

$$S \geq 10 I$$

Substituting for S, (2) and I, (12)

$$[4.33 \times 10^{-20}] M^2 P_T \geq (10)[2.17 \times 10^{-20}] \frac{PM^3 P_T W_{BB}}{W_{SS}\, 9\delta_I^3}$$

$$[4.33 \times 10^{-20}] \geq [2.41 \times 10^{-20}] \frac{PM W_{BB}}{W_{SS} \delta_I^3}$$

$$W_{SS} \geq [5.57 \times 10^{-1}] \frac{PM W_{BB}}{\delta_I^3}$$

Assume,

$$W_{BB} = 20 \text{ KHz}$$

Therefore,

$$W_{SS} \geq [1.11 \times 10^4] \frac{PM}{\delta_I^3} \tag{13}$$

(To Communicate)

In the analysis of Air-to-Ground Intercept, 3 separate cases have been evaluated where $Q \geq 10[N_I + I^Q]$. Two cases were studied with the intercepter standing-off from the communication network. The first case is limited by interference. Case two includes both thermal noise and communication interference. Case three's interpretation involves the intercept over the communication network.

CASE 1 Intercept Standing Off (Interference limited)

Interference due to the ℓ^{th} source at the intercepter , I_ℓ^Q :

$$I_\ell^Q = \frac{P_T G_{F_\ell I} G_{IF_\ell} \lambda^2 W_I}{(4\pi)^2 R_{I_\ell}^2 L_I W_{SS}}$$

$$I_\ell^Q = \frac{G_{F_\ell I} G_{IF_\ell}}{\left[\frac{(4\pi)^2}{\lambda^2} L_I\right]} \frac{1}{R_{I_\ell}^2} \frac{P_T W_I}{W_{SS}} \tag{14}$$

Let

$G_{F_\ell I} = 0dB = 1.0$ $\quad f = 3\times10^8$ Hz

$G_{IF_\ell} = 0dB = 1.0$ $\quad \lambda = 6.214\times10^{-4}$ statute mi

$L_I = 3dB = 10^{.3}$

$$\left[\frac{(4\pi)^2}{\lambda^2} L_I\right] = \frac{(4\pi)^2(10^{.3})}{(6.214\times10^{-4})^2} = 8.16\times10^8 \;(1/mi^2)$$

Substituting into (14)

$$I_\ell^Q = [1.23\times10^{-9}]\frac{1}{R_{I_\ell}^2}\;\frac{P_T W_I}{W_{SS}} \tag{15}$$

Finding the total interference power,

$$I^Q = \sum_{\ell=1}^{L} I_\ell^Q = [1.23\times10^{-9}]\,L\,\frac{P_T W_I}{W_{SS}}\left\{\frac{1}{L}\sum_{\ell=1}^{L}\frac{1}{R_{I_\ell}^2}\right\} \tag{16}$$

Because the intercepter is standing-off, assume,

$R_{I_\ell} \neq f(\langle R_F\rangle)$, but rather

R_I is related to $\sqrt{\dfrac{AREA}{\pi}}$ .Assume

$$R_I = R_{I_{MIN}} \longrightarrow R_{I_{MIN}} + \sqrt{\frac{AREA}{\pi}}$$

Therefore,

R_I is uniform on $N\sqrt{\dfrac{AREA}{\pi}}\,,\;(N+1)\sqrt{\dfrac{AREA}{\pi}}$

$$\sqrt{\frac{AREA}{\pi}} = \sqrt{\frac{5026.55}{\pi}} = 40 \text{ miles}$$

R_I is uniform on $N[40]\,,\;(N+1)[40]$ miles

$$E\left\{\frac{1}{R_{I_1}^2}\right\} = \frac{1}{40}\int_{N(40)}^{(N+1)(40)} \frac{1}{X^2}\,dx$$

$$= -\frac{1}{40}\;\frac{1}{X}\Bigg|_{N(40)}^{N+1(40)}$$

$$= \frac{1}{40}\left[\frac{1}{(40)N} - \frac{1}{(40)N+1}\right]$$

$$= \frac{N+1-N}{(40)^2(N+1)(N)} = \frac{1}{(40)^2(N)(N+1)} \tag{17}$$

Substituting (17) into (16) yields

$$I^Q = \frac{\left[1.23\times10^{-9}\right]}{(N)(N+1)(1600)}\;\frac{L\,P_T W_I}{W_{ss}}$$

$$I^Q = \frac{7.66\times10^{-13}}{(N)(N+1)}\;\frac{L\,P_T W_I}{W_{ss}} \tag{18}$$

For intercept,

$$Q \geq 10\left[N_I + I^Q\right]$$

Using equations (6) and (18),

$$\left[4.88\times10^{-11}\right]\frac{P_T W_I}{W_{ss}} \geq (10)(10^{-20})\,W_I + (10)\,\frac{7.66\times10^{-13}}{(N)(N+1)}\;\frac{L\,P_T W_I}{W_{ss}} \tag{19}$$

where the intercepter noise power spectral density is assumed to be 10^{-20} watts/Hz.

Assume Q receiver is interference limited, (this will be discussed later)

$$\left[4.88\times10^{-11}\right]\frac{P_T W_I}{W_{ss}} > \frac{7.66\times10^{-12}}{(N)(N+1)}\;\frac{PM\,P_T W_I}{W_{ss}} \tag{20}$$

To permit intercept

$$\left[4.88 \times 10^{-11}\right] > 7.66 \times 10^{-12} \frac{PM}{(N)(N+1)}$$

To avoid intercept

$$\frac{7.66 \times 10^{-12}}{(N)(N+1)} PM > 4.88 \times 10^{-11}$$

$$\frac{PM}{(N)(N+1)} > 6.4 \qquad \text{or,}$$

$$M > \frac{6.4\,(N)(N+1)}{P} \qquad \text{(To Avoid Intercept) (21)}$$

CASE 2 Intercepter Standing-Off (when not interference limited)

Returning to equation (19)

$$\left[4.88 \times 10^{-11}\right] \frac{P_T W_I}{W_{SS}} > 10^{-19} W_I + \frac{7.66 \times 10^{-12}}{(N)(N+1)} \frac{L\, P_T W_I}{W_{SS}}$$

To solve for M

$$\left[4.88 \times 10^{-11}\right] P_T > 10^{-19} W_{SS} + \frac{7.66 \times 10^{-12}}{(N)(N+1)} PM\, P_T$$

$$\left[4.88 \times 10^{-11}\right] P_T - 10^{-19} W_{SS} > 7.66 \times 10^{-12} \frac{PMP_T}{(N)(N+1)}$$

To Avoid Interception,

$$M > \frac{\left(\left[4.88 \times 10^{-11}\right] P_T - 10^{-19} W_{SS}\right)(N)(N+1)}{7.66 \times 10^{-12}\, P_T P}$$

$$> \frac{4.88 \times 10^{-11}}{7.66 \times 10^{-12}} \frac{(N)(N+1)}{P} - \frac{10^{-19}}{7.66 \times 10^{-12}} \frac{W_{SS}(N)(N+1)}{P_T P}$$

$$M > 6.37 \frac{(N)(N+1)}{P} - 1.31 \times 10^{-8} \frac{W_{SS}(N)(N+1)}{P_T P} \qquad (22)$$

(To Avoid Interception)

CASE 3 Intercept over Communication Network

Using equation (15)

$$I_\ell^Q = \left[1.23 \times 10^{-9}\right] \frac{1}{R_{I_\ell}^2} \frac{P_T W_I}{W_{SS}}$$

and reflecting the closeness of the intercepter to the network by letting

$$R_{I_\ell} = \alpha_\ell \langle R_F \rangle$$

we obtain

$$I^Q = \sum_{\ell=1}^{L} I_\ell^Q = \left[1.23 \times 10^{-9}\right] \frac{P_T W_I}{W_{SS}} L \left\{ \frac{1}{L} \sum_{\ell=1}^{L} \frac{1}{\alpha_\ell^2 \langle R_F \rangle^2} \right\}$$

$$= \frac{1.23 \times 10^{-9}}{\langle R_F \rangle^2} \frac{M P P_T W_I}{W_{SS}} E\left\{ \frac{1}{\alpha^2} \right\}$$

Since by definition, see (1a),

$$\langle R_F \rangle^2 = \frac{5026.55}{\pi M} = \frac{1.6 \times 10^3}{M}$$

$$I^Q = \left[7.66 \times 10^{-13}\right] \frac{M^2 P P_T W_I}{W_{SS}} E\left\{ \frac{1}{\alpha^2} \right\} \qquad (23)$$

Assume R_{I_2} is uniform between $\delta_Q \langle R_F \rangle$ and $(8+\delta)\langle R_F \rangle$

Therefore,

$$E\left\{\frac{1}{\alpha^2}\right\} = \frac{1}{8}\int_{\delta_Q}^{8+\delta_Q} \frac{1}{X^2}\, dx$$

$$= \frac{1}{8(-1)} \left.\frac{1}{X}\right|_{\delta_Q}^{8+\delta_Q}$$

$$= \frac{1}{8}\left[\frac{1}{\delta_Q} - \frac{1}{8+\delta_Q}\right]$$

$$\cong \frac{1}{8\delta_Q} \qquad (24)$$

Using (24) in (23) yields

$$I^Q = \frac{7.66 \times 10^{-13}}{8} \, \frac{M^2 P P_T W_I}{\delta_Q W_{ss}}$$

$$I^Q = \left[9.58 \times 10^{-14}\right] \frac{M^2 P P_T W_I}{\delta_Q W_{ss}} \qquad (25)$$

For Intercept to Occur

$$Q \geq 10\left[N_I + I^Q\right]$$

It follows then for intercept

$$\left[4.88 \times 10^{-11}\right] \frac{P_T W_I}{W_{ss}} \geq 10(10^{-20}) W_I + 10(9.58 \times 10^{-14}) \frac{M^2 P P_T W_I}{\delta_Q W_{ss}}$$

$$\left[4.88 \times 10^{-11}\right] \frac{P_T}{W_{ss}} \geq 10^{-19} + 9.58 \times 10^{-13} \frac{M^2 P P_T}{\delta_Q W_{ss}}$$

Assuming interference limited, (to be confirmed later)

$$\left[4.88 \times 10^{-11}\right] \frac{P_T}{W_{ss}} \geq 9.58 \times 10^{-13} \frac{M^2 P P_T}{\delta_Q W_{ss}} \tag{26}$$

To Avoid Intercept

$$\left[9.58 \times 10^{-13}\right] \frac{M^2 P P_T}{\delta_Q W_{ss}} > \left[4.88 \times 10^{-11}\right] \frac{P_T}{W_{ss}}$$

$$\left[9.58 \times 10^{-13}\right] \frac{M^2 P}{\delta_Q} > \left[4.88 \times 10^{-11}\right]$$

$$\frac{M^2 P}{\delta_Q} > 50.94 \qquad \text{(To Avoid Interception)} \tag{27}$$

Using the three different cases,

<u>CASE 1</u> intercept standing-off

<u>To Communicate</u> (from 13)

$$MP \leq \frac{W_{ss}\, \delta_I^{\,3}}{1.11 \times 10^{4}}$$

<u>To Avoid Interception</u> - Interference limited (from 21)

$$MP \geq 6.4(N)(N+1)$$

CASE 2 - Intercept Standing-off

To Communicate (13)

$$MP < \frac{W_{ss}\delta_I^3}{1.11 \times 10^4}$$

To Avoid Intercepter (22)

$$MP > 6.37(N)(N+1) - \frac{[1.31 \times 10^{-8}] W_{ss}(N)(N+1)}{P_T}$$

CASE 3 - Intercept over the Communicator's Network

To Communicate $$MP < \frac{W_{ss}\delta_I^3}{1.11 \times 10^4}$$ (from 13)

To Avoid Interception - interference limited

$$M^2P > 50.94 \qquad (27)$$

Earlier we assumed that equation (19) is interference limited,

$$[4.88 \times 10^{-11}] \frac{P_T W_I}{W_{ss}} > 10^{-19} W_I + \frac{7.66 \times 10^{-12}}{(N)(N+1)} \frac{L P_T W_I}{W_{ss}}$$

where the thermal noise,

$$N_I = 10^{-19} W_I$$

is such a small number, that when we add it to the interference of the

intercept receiver it makes little difference. Evaluating the ratio of interference versus thermal noise

$$\frac{\text{INTERFERENCE}}{\text{THERMAL NOISE}} = \frac{7.66 \times 10^{-12}}{10^{-19}} \; \frac{L P_T}{W_{ss}(N)(N+1)}$$

$$\frac{\text{INTERFERENCE}}{\text{THERMAL NOISE}} = 7.66 \times 10^{7} \; \frac{M P P_T}{W_{ss}(N)(N+1)} \qquad (28)$$

let

$P = .2$
$P_T = 10$ W
$N = 1$

and substituting into (28)

$$\frac{\text{INTERFERENCE}}{\text{THERMAL NOISE}} = 7.66 \times 10^{7} \; \frac{M(.2)(10)}{W_{ss}(1)(2)}$$

$$\frac{\text{INTERFERENCE}}{\text{THERMAL NOISE}} = 7.66 \times 10^{7} \; \frac{M}{W_{ss}}$$

$$\left[\frac{\text{INTERFERENCE}}{\text{THERMAL NOISE}}\right]_{dB} = 79 + 10 \text{LOG } M - 10 \text{LOG } W_{ss} \qquad (29)$$

We also assumed equation (26) is interference limited

$$[4.88 \times 10^{-11}] \frac{P_T W_I}{W_{SS}} \geq 10^{-19} W_I + 9.58 \times 10^{-13} \frac{M^2 P P_T}{\delta_Q W_{SS}}$$

$$\frac{\text{INTERFERENCE}}{\text{THERMAL NOISE}} = \frac{9.58 \times 10^{-13}}{10^{-19}} \frac{M^2 P P_T}{\delta_Q W_{SS}}$$

$$\frac{\text{INTERFERENCE}}{\text{THERMAL NOISE}} = [9.58 \times 10^{6}] \frac{M^2 P P_T}{\delta_Q W_{SS}} \tag{30}$$

let

$P = .2$
$P_T = 10$ W
$\delta_Q = 1$ (δ_Q being a dominating variable)

and substitute into (30) gives

$$\frac{\text{INTERFERENCE}}{\text{THERMAL NOISE}} = \frac{(9.58 \times 10^{6})(.2)(10)}{1} \frac{M^2}{W_{SS}}$$

$$= (1.92 \times 10^{8}) \frac{M^2}{W_{SS}}$$

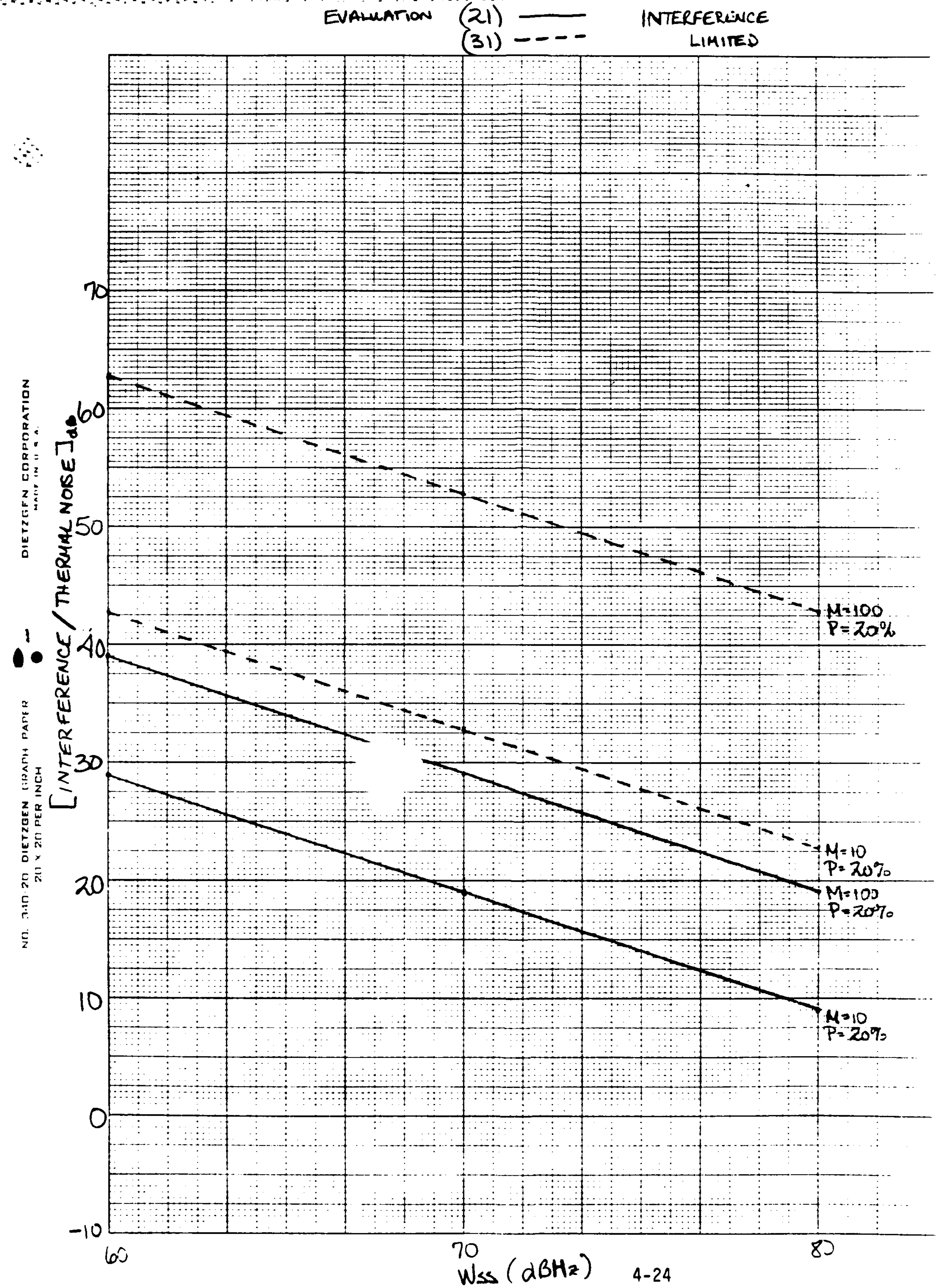
$$\left[\frac{\text{INTERFERENCE}}{\text{THERMAL NOISE}}\right]_{dB} = 82.8 + 20 \log M - 10 \log W_{SS} \tag{31}$$

The first graph following, will show why our assumption to intercept is interference limited. The other graphs will be the scenario snapshots that show the areas at which one has "no communication with no intercept", "communication with interception", "no communication with intercept", and "no communication with no intercept".

INTERFERENCE LIMITED

Having a spread spectrum bandwidth of 60 dB Hz, an interference to thermal noise ratio of 29.94 dB, and M equal to 10, with a probability of 20% of these users being on the air at one time, if we increase W_{ss} to 80 dB Hz then the ratio of interference to thermal noise decreases to 9.94 dB. This implies that either the thermal noise became greater, which we know can not be true, because thermal noise is considered to be constant, or interference is decreasing, which can be a good assumption. Therefore, when we increase W_{ss}, the interference becomes smaller, making the ratio of interference to thermal noise smaller.

Another observation is that if we had 60 dB Hz of spread spectrum bandwidth and this caused our interference to noise ratio to be 29.94 dB with only ten users, if we increased W_{ss} to 80 dB Hz and let M equal to 100 with P equal to .2, our ratio is less than 20 dB. Through our analysis and the graph,one can see that the intercept is almost always inteference limited.



EVALUATION (21) ——— INTERFERENCE
(31) - - - - LIMITED
[INTERFERENCE / THERMAL NOISE]dB
70
60
50
40
30
20
10
0
−10
60
70
80
Wss (dBHz)
M=100
P=20%
M=10
P=20%
M=100
P=20%
M=10
P=20%
NO. 340-20 DIETZGEN GRAPH PAPER
20 X 20 PER INCH
DIETZGEN CORPORATION
MADE IN U.S.A.

AIR-TO-GROUND INTERCEPT

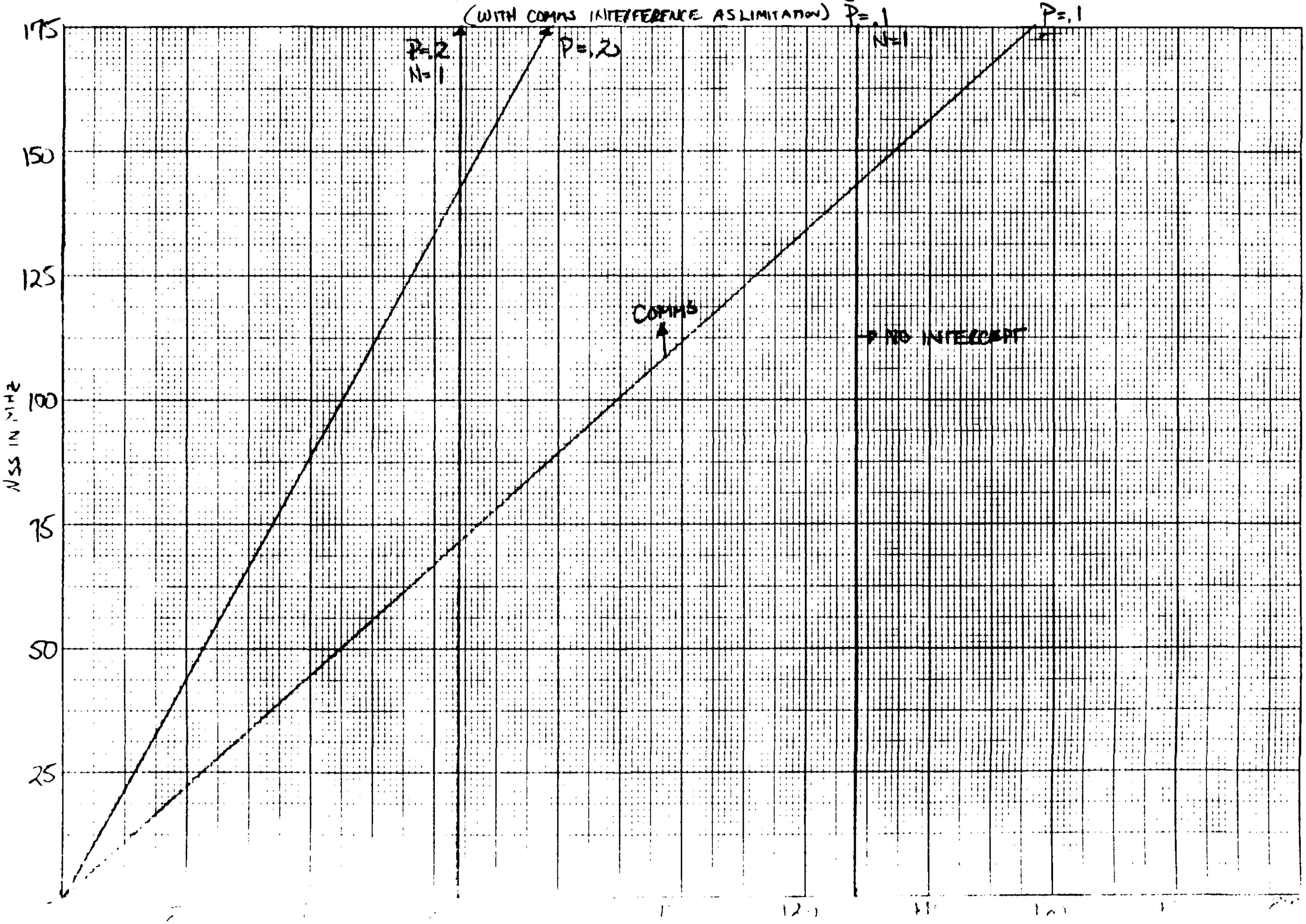
SCENARIO SNAPSHOT #1

Case 1 and Case 2

Graphically, Case 1 and Case 2 are virtually the same, except the intercepter line in Case 2 has a slight slant to the left. This implies that at a higher spread spectrum bandwidth, a lower limit of M is obtained. Studying this snapshot, with P equal to .1 and N equal to 1, M has tobe at a minimum of 128 users with W_{ss} larger than 143 MHz. Even as the probability of the number of users increases to .2, we still need M to be at least sixty-four with W_{ss} larger than 143 MHz.

With the intercepter standing-off, our analysis and the snapshot shows that no matter where one is in the communication network, he is easily intercepted if we use a 100 MHz system. However, within this study, we have not taken into account the enemies own communicators interferring with the enemy's intercept.

$1/R^2$ INTERCEPT WITH STAND-OFF INTERCEPTOR (CASE 1)
(WITH COMMS INTERFERENCE AS LIMITATION)



AIR-TO-GROUND INTERCEPT

SCENARIO SNAPSHOT #2

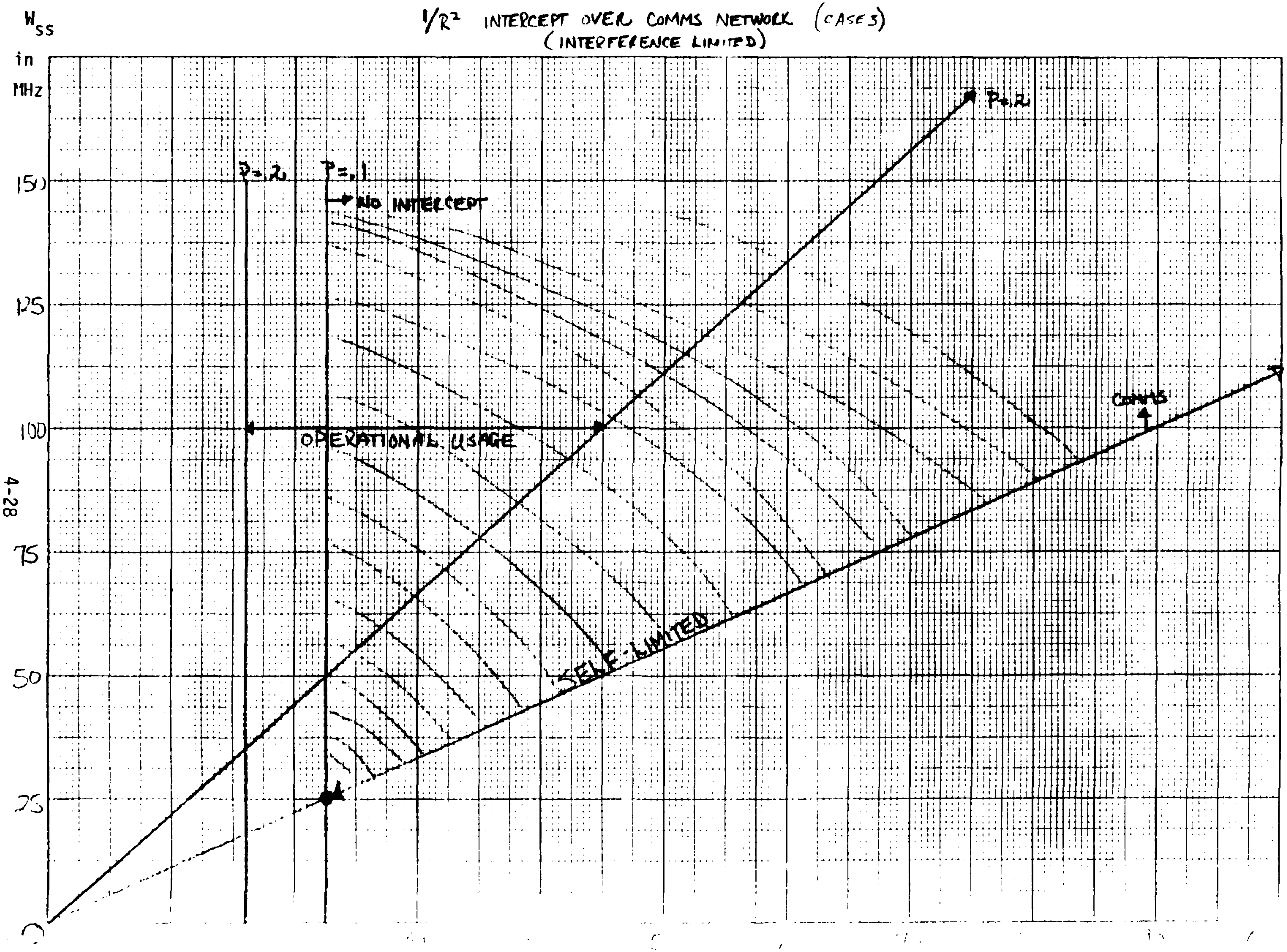
Case 3

Observing the point on the snapshot where W_{SS} is 25 MHz, M is 22.6 and the probability of all users being on the air at one time is .1, one must increase M to avoid interception. If we increase M, then the spread spectrum bandwidth must also be increased or else the situation where there is no communication and no intercept arises. The communicator's network is self-limited due to its own communicator's interference.

If operational usage is 100 MHz and the probability of being on the air is .2, to avoid interception, there must be a minimum of sixteen users and at most, forty-five users communicating at all times. If the number of users decends below the minimum of sixteen, interception becomes possible, whereas, if the forty-five user maximum is exceeded, it is effectively blocked.

From Graph, very large spread spectrum bandwidths are needed to avoid intercept.

$1/R^2$ INTERCEPT OVER COMMS NETWORK (CASE 3)
(INTERFERENCE LIMITED)



4.3 GROUND-TO-GROUND INTERCEPT

The power of the transmitted communication signal at the communication receiver, denoted S, is given as the following expression:

$$S = \frac{P_t\, G_{tr}\, G_{rt}\, \lambda^2}{(4\pi)^2\, R_c^{\,4}\, K_c\, L_c}$$

where

P_t = Transmitted Communication Power

G_{tr} = Transmitted Antenna Gain in the Direction of the Communication Receiver (relative to omni)

G_{rt} = Communication Receiver Antenna Gain in the Direction of the transmitter (relative to omni)

λ = Wavelength of Center Frequency of the Communication Signal

R_c = Communication Distance

K_c = Constant of Attenuation,

L_c = Loss at the Communication Receiver

Setting

$$\frac{1}{\alpha(R_c)} = \frac{\lambda^2}{(4\pi)^2\, R_c^{\,4}\, K_c}$$

where

$\alpha(R_c)$ = Attenuation at the range of the communicator,

and substituting into S, One has:

$$S = \frac{P_t\, G_{tr}\, G_{rt}}{\alpha(R_c)\, L_c}$$

Derived from a propagation curve set,[16]

$$\alpha(R_c) = C(R_o)\alpha_{fs}(R_o)\left[\frac{R_c}{R_o}\right]^4$$

where

$C(R_o)$ = Distance between Ø feet and free space (in feet) $\approx$ 36dB $= 10^{3.6}$

$\alpha_{fs}(R_o)$ = Free space Attenuation.(in dB) $\approx$ 86.5dB $= 10^{8.65}$

let

$R_o = 1$ mile

$R_c \leq 20$ miles

$f = 300$ MHz

Good Soil

Vertical Polarization

NOTE: $1/R^4$ range is not very accurate after 10 miles, the slope becomes steeper than $1/R^4$.

$$\alpha(R_c) = 10^{3.6}\, 10^{8.65}\, R_c^{\,4}$$

$$= 10^{12.25}\, R_c^{\,4} \qquad (1)$$

Substituting into S,

$$S = \frac{P_t\, G_{tr}\, G_{rt}}{10^{12.25}\, R_c^{\,4}\, L_c}$$

Define $\langle R_f \rangle^2 \quad \frac{A}{\pi M}$

where

R_f is the radius of friendly radio net operation

A is the area in square miles

M is the total possible number of simultaneous transmitters

$$R_c \equiv a_1 \langle R_f \rangle$$

where a_1 is defined as the characteristic range between communicators in a network.

$$R_c^{\,4} \equiv a_1^{\,4} \langle R_f \rangle^4$$

$$\equiv \frac{a_1^{\,4}\, A^2}{\pi^2\, M^2} \qquad (2)$$

therefore:

$$S = M^2\, P_t \left[\frac{G_{tr}\, G_{rt}\, \pi^2}{10^{12.25}\, a_1^{\,4}\, A^2\, L_c} \right]$$

which we assume has to be greater than or equal to 10 dB for hearability.

Let K_1 equal the equation inside brackets:

$$S = M^2 P_t K_1 \tag{3}$$

The power of the transmitted signal received at the intercept receiver, denoted Q, is given by the following equation:

$$Q = \frac{P_t G_{ti} G_{it} \lambda^2 W_i}{(4\pi)^2 R_i^4 K_i L_i W_{ss}}$$

where

G_{ti} = Transmitter antenna gain in the direction of the intercept receiver (relative to omni)

G_{it} = Intercept receiver antenna gain in the direction of the transmitter (relative to omni)

W_i = Intercept bandwidth

W_{ss} = Spread Spectrum bandwidth

R_i = Intercept range

K_i = Constant of Attenuation

L_i = Loss at intercept receiver

Assuming K_1 = 36.38 dB = 4345 and using (1) and substituting, gives,

$$Q = \frac{P_t W_i}{W_{ss}} \left[\frac{G_{ti} G_{it}}{10^{12.25} R_i^4 L_i} \right] \tag{4}$$

and letting K_2 equal the equation in brackets:

$$Q = \frac{P_t W_i K_2}{W_{ss}} \tag{5}$$

Next, we need to look at the communicator's interference power from one friendly transmitter, I_1

$$I_1 = \frac{P_t G_{F_1R} G_{RF_1} W_{bb}}{\left[\dfrac{(4\pi)^2 K_{F1}}{\lambda^2} \right] R_{F1}^4 L_c \; 2W_{ss}}$$

where

G_{F_1R} = Transmitter antenna gain in the direction of the communication receiver (relative to omni)

G_{RF_1} = Communication receiver gain in the direction of the friendly transmitter (relative to omni)

W_{bb} = Baseband bandwidth

K_{F_1} = Constant of attenuation

R_{F_1} = Friendly transmitter distance

Assuming K_{F_1} = 36.38 dB = 4345 and using (1) and substituting,

$$I_1 = \frac{P_t\, G_{tr}\, G_{rt}}{10^{12.25}\, R_{F_1}^{\;4}\, L_c} \quad \frac{W_{bb}}{2W_{ss}} \tag{6}$$

Taking an average of the communications interference power for one friendly transmitter:

$$I = \sum_{1=1}^{L} I_1 \qquad L = PM$$

where

L = Number of actual users at anyone time

P = Probability of being on the air (Users duty cycle)

M = Total number of possible users

$$I = \frac{P_t\, G_{tr}\, G_{rt}\, W_{bb}\, L}{10^{12.25}\, L_c\, 2W_{ss}} \left[\frac{1}{L} \sum_{1=1}^{L} \frac{1}{K_{F_1}^{\;4}} \right] \tag{7}$$

Assume R_{F_1} is uniform over $\delta_F, \delta_F + D_F$, where δ_F is the distance to the closest friendly interferer, and $\delta_F + D_F$ is the distance to the furthest friendly interferer.

$$\frac{1}{L} \sum_{1=1}^{L} \frac{1}{R_{F_1}^{\;4}} \cong E\left\{\frac{1}{R_{F_1}^{\;4}}\right\} \frac{1}{D_F} \int_{\delta_F}^{\delta_F+D_F} \frac{1}{X4}\, dx$$

$$\frac{1}{-3\, D_F} \quad x^{-3} \Big|_{\delta_F}^{\delta_F + D_F}$$

$$\frac{1}{L}\sum_{l=1}^{L}\frac{1}{R_{F_l}{}^{4}} \cong \frac{1}{3\ D_F \sigma_F{}^3} \qquad (8)$$

NOTE: We are really only interested in the closest friendly interferer, σ_F.

Therefore, using (8) and substituting back into (7)

$$I = \frac{P_t\ G_{tr}\ G_{rt}\ W_{bb}\ L}{10^{12.25}\ L_c\ 2W_{ss}\ 3D_F \sigma_F{}^3}$$

$$= \frac{P_t\ PM\ G_{tr}\ G_{rt}\ W_{bb}}{10^{12.25}\ L_c\ 2W_{ss}\ 3D_F \sigma_F{}^3} \qquad (8.5)$$

let

$D_F = a_2 \langle R_F \rangle$

$\sigma_F = a_3 \langle R_F \rangle$

where a_2 and a_3 are defined as the total range of network operations and the range to the dominant friendly interferer, respectively.

$$D_F \sigma_F{}^3 = a_2\ a_3{}^3 \langle R_F \rangle^4 = a_2\ a_3{}^3\ \frac{A^2}{\pi^2\ M^2} \qquad (9)$$

Substituting (9) back into (8.5)

$$I = \frac{P_t\ PM^3\ G_{tr}\ G_{rt}\ W_{bb} \pi^2}{10^{12.25}\ L_c\ 2W_{ss}\ 3a_2\ a_3{}^3\ A^2}$$

$$I = \frac{PM^3\ P_t\ W_{bb}}{W_{ss}} \left[\frac{G_{tr}\ G_{rt} \pi^2}{(6)\ 10^{12.25}\ L_c\ a_2\ a_3{}^3\ A^2}\right] \qquad (10)$$

Letting K_3 equal the equation in brackets:

$$I = \frac{PM^3\ P_t\ W_{bb}\ K_3}{W_{ss}} \qquad (11)$$

The noise of the intercepter, N_I, is as follows:

$$N_I = N_{0I} W_I$$

$$N_I = 10^{-20.4} N_{fI} W_I \tag{12}$$

where

N_{0I} = The thermal noise

N_{fI} = Noise due to the friendly interferer

In order to communicate, assuming that the communicator's receiver is interference limited and not thermal noise limited,

$$S \geq 10I$$

Replacing S and I with equations (3) and (11)

$$M^2 P_t K_1 \geq \frac{10 PM^3 P_t W_{bb}}{W_{ss}} K_3$$

$$W_{ss} \geq 10 PM W_{bb} \frac{K_3}{K_1}$$

$$\geq PM W_{bb} \left[\frac{10 G_{tr} G_{rt} \pi^2 10^{12.25} a_1{}^4 A^2 L_c}{(6) 10^{12.25} L_c a_2 a_3{}^3 A^2 G_{tr} G_{rt} \pi^2} \right]$$

$$\geq PM W_{bb} \left[\frac{10 a_1{}^4}{6 a_2 a_3{}^3} \right]$$

$$W_{ss} \geq PM W_{bb} \left[\frac{5 a_1{}^4}{3 a_2 a_3{}^3} \right] \quad \text{(To Communicate)} \tag{13}$$

Note that a_3, the range to the closest friendly interferer, is the dominating factor when viewed from a communication network standpoint.

Likewise, for one to intercept,

$$Q \geq 10 N_I$$

Replacing Q and N_I with equations (5) and (12):

$$\frac{P_t\ W_i}{W_{ss}}\quad K_2 \geq 10\quad (10^{-20.4}\ N_{fI}\ )\ \ W_i$$

$$\frac{P_t}{W_{ss}} \geq \frac{10^{-19.4}\ N_{fI}}{K_2}$$

To avoid intercept,

$$W_{ss} \geq \frac{P_t\ K_2}{10^{-19.4}\ N_{fI}}$$

Substituting K_2,

$$W_{ss} \geq \frac{P_t}{10^{-19.4}\ N_{fI}}\qquad \frac{G_{ti}\ G_{it}}{10^{12.25}\ R_i^{\ 4}\ L_i}$$

Letting,

N_{fI} = 4 dB = 2.51

G_{ti} = 0 dB = 1.0

G_{it} = 6 dB = 3.98

L_i = 6 dB = 3.98

$$W_{ss} \geq \frac{P_t}{10^{-6.75}\ R_i^{\ 4}}\qquad \text{(to avoid interception)}\qquad (14)$$

The following scenario snapshots, using equations (13) and (14), show the areas at which one can "communicate with no interception", "communicate with interception", "not communicate with interception", and "not communicate and not be intercepted".

SCENARIO SNAPSHOT #1

To Communicate,

$$W_{ss} \geq PM\ W_{bb} \left[\frac{5a_1^{\ 4}}{3a_2\ a_3^{\ 3}} \right] \qquad \text{from (13)}$$

letting

$a_1 = 1$ — a_1 = Characteristic Range of the Communication

$a_2 = 2$ — a_2 = Total Range of Operations

$a_3 = .1$ — a_3 = Range to Dominating Friendly Interferer

$W_{bb} = 25 \times 10^3$ Hz

therefore

$$W_{ss_{min}} \cong 20.8\ PM\ \text{MHz}$$

$$M = \frac{W_{ss_{min}}}{P\ (20.8)} \qquad \text{(To Communicate)}$$

letting

$W_{ss_{min}}$ = 0 to 425 MHz in increments of 25 MHz , and

P = .1 to .5 in increments of .1

To Avoid Interception,

$$W_{ss} > \frac{P_t}{10^{-6.75} \; R_i^{\,4}} \qquad \text{from (14)}$$

letting

P_t = 10 Watts , and

R_i = 1 to 5 miles in increments of 1

It is worth noting that as the intercept range gets larger, the vertical lines gets closer to zero.

SCENARIO SNAPSHOT #2

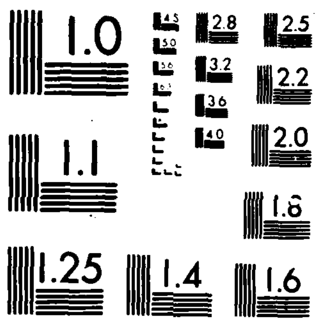
The only difference between Scenario Snapshop #1 and #2 is the P_t in the equation To Avoid Interception. P_t equals 50 Watts.

SCENARIO SNAPSHOT #3

In this particular snapshot, snapshot #1 and #2 are combined to show that when one increases P_t to communicate without interception, a larger spread spectrum bandwidth, W_{ss}, is needed along with an increase in the number of users. R_i is shown at one mile only.

AD-A163 985 ON ACHIEVING NETWORK LPI (LINK PARAMETER INTERACTIONS) FOR SPREAD SPECTRUM COMMUNICATIONS(U) E-SYSTEMS INC FAIRFAX VA MELPAR DIV W J O'BRIEN ET AL. OCT 85 2/3

UNCLASSIFIED ARO-21611.3-EL DAAG29-84-C-0008 F/G 17/2.1 NL



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963 A

THE INTERCEPTOR'S SPREAD SPECTRUM BANDWIDTH

POWER IN WATTS: 10.00

RI IN MILES	WSS IN MHZ
0.50	899.74639893
1.00	56.23414993
1.50	11.10797977
2.00	3.51463437
2.50	1.43959415
3.00	0.69424874
3.50	0.37473807
4.00	0.21966465
4.50	0.13713555
5.00	0.08997463
5.50	0.06145387
6.00	0.04339055
6.50	0.03150262
7.00	0.02342113
7.50	0.01777277
8.00	0.01372904
8.50	0.01077270
9.00	0.00857097
9.50	0.00690408
10.00	0.00562341

THE INTERCEPTOR'S SPREAD SPECTRUM BANDWIDTH

POWER IN WATTS: 50.00

RI IN MILES	WSS IN MHZ
0.50	4498.73193359
1.00	281.17074585
1.50	55.53989410
2.00	17.57317162
2.50	7.19797039
3.00	3.47124338
3.50	1.87369049
4.00	1.09832323
4.50	0.68567771
5.00	0.44987315
5.50	0.30726936
6.00	0.21695271
6.50	0.15751308
7.00	0.11710566
7.50	0.08886383
8.00	0.06864520
8.50	0.05386349
9.00	0.04285486
9.50	0.03452040
10.00	0.02811707

TO COMMUNICATE WITHIN R**4 PROPAGATION

A1= 1.0
A2= 2.0
A3= 0.1

P= 0.1

M	WSS IN MHZ
0.0	0
12.0	25
24.0	50
36.0	75
48.0	100
60.0	125
72.0	150
84.0	175
96.0	200
108.0	225
120.0	250
132.0	275
144.0	300
156.0	325
168.0	350
180.0	375
192.0	400
204.0	425

P= 0.2

M	WSS IN MHZ
0.0	0
6.0	25
12.0	50
18.0	75
24.0	100
30.0	125
36.0	150
42.0	175
48.0	200
54.0	225
60.0	250
66.0	275
72.0	300
78.0	325
84.0	350
90.0	375
96.0	400
102.0	425

P= 0.3

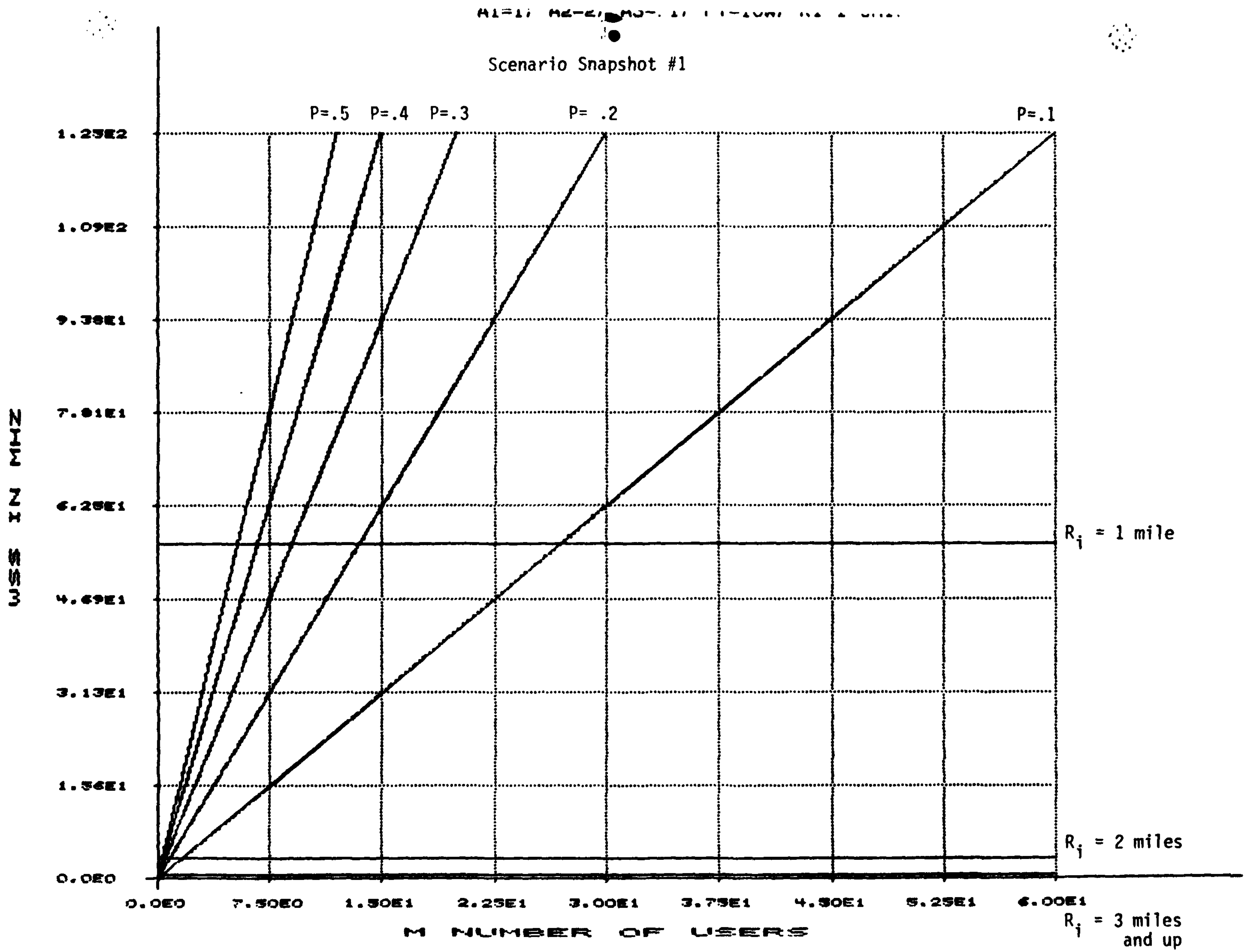
M	WSS IN MHZ
0.0	0
4.0	25
8.0	50
12.0	75
16.0	100
20.0	125
24.0	150
28.0	175
32.0	200
36.0	225
40.0	250
44.0	275
48.0	300
52.0	325
56.0	350
60.0	375
64.0	400
68.0	425

P= 0.4

M	WSS IN MHZ
0.0	0
3.0	25
6.0	50
9.0	75
12.0	100
15.0	125
18.0	150
21.0	175
24.0	200
27.0	225
30.0	250
33.0	275
36.0	300
39.0	325
42.0	350
45.0	375
48.0	400
51.0	425

P= 0.5

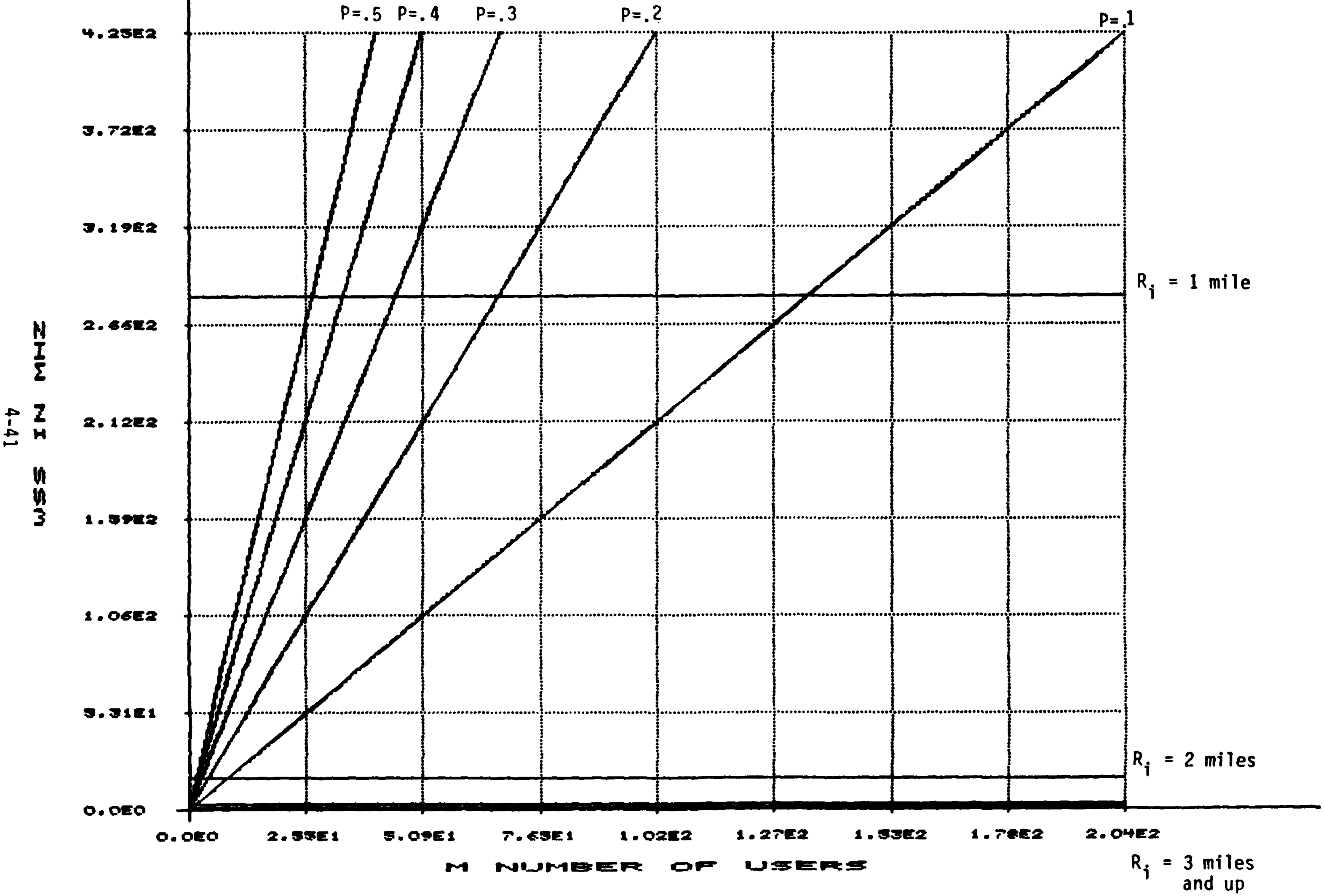
M	WSS IN MHZ
0.0	0
2.4	25
4.8	50
7.2	75
9.6	100
12.0	125
14.4	150
16.8	175
19.2	200
21.6	225
24.0	250
26.4	275
28.8	300
31.2	325
33.6	350
36.0	375
38.4	400
40.8	425



Scenario Snapshot #1
P=.5
P=.4
P=.3
P= .2
P=.1
1.25E2
1.09E2
9.38E1
7.81E1
6.25E1
4.69E1
3.13E1
1.56E1
0.0E0
WSS IN MHZ
0.0E0
7.50E0
1.50E1
2.25E1
3.00E1
3.75E1
4.50E1
5.25E1
6.00E1
M NUMBER OF USERS
R_i = 1 mile
R_i = 2 miles
R_i = 3 miles and up

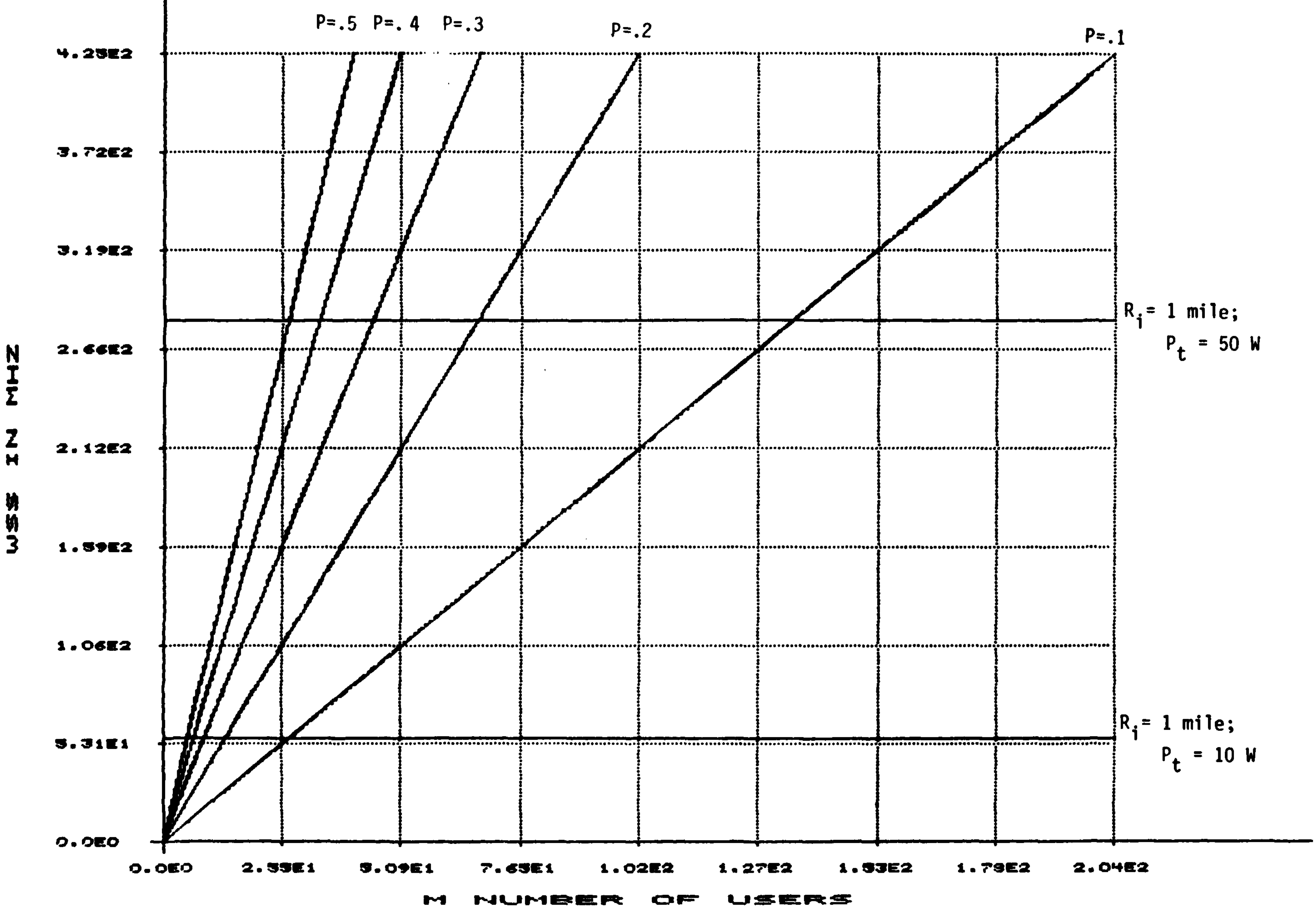
A1=1; A2=2; A3=.1; PI=50W; RI=1-5MI.

Scenario Snapshot #2



A1=1; A2=2 A3=.1; PT=10,50W; RI=1MI.

Scenario Snapshot #3



SCENARIO SNAPSHOT #4

In order to communicate,

$$W_{ss} \geq PM\, W_{bb} \left[\frac{5a_1^{\,4}}{3a_2\, a_3^{\,3}} \right], \qquad \text{from (13)}$$

which is the same equation for scenario snapshots #1 - #3.

In these next three snapshots, we will let

$$a_1 = 1$$

$$a_2 = 1$$

$$a_3 = .1$$

$$W_{bb} = 25 \times 10^3 \text{ Hz}$$

therefore, to communicate,

$$W_{ss_{min}} = 41.7 \text{ PM MHz}$$

again letting

$W_{ss_{min}}$ = 0 to 425 MHz in increments of 25 MHz, and

P = .1 to .5 in increments of .1

To avoid interception,

$$W_{ss} \geq \frac{P_t}{10^{-6.75} R_i^{\,4}} \qquad \text{from (14)}$$

P_t = 10 Watts

R_i = 1 to 5 miles in increments of 1.

SCENARIO SNAPSHOT #5

Here we changed the power to 50 Watts from the avoiding intercept equation and extended the communication lines out to 425 MHz.

SCENARIO SNAPSHOT #6

Snapshots #4 and #5 are combined for the same reason as scenario snapshot #3. This snapshot shows what happens when we increased the power with intercept range being one mile.

TO COMMUNICATE WITHIN R**4 PROPAGATION

A1= 1.0
A2= 1.0
A3= 0.1

P= 0.1

M	WSS IN MHZ
0.0	0
6.0	25
12.0	50
18.0	75
24.0	100
30.0	125
36.0	150
42.0	175
48.0	200
54.0	225
60.0	250
66.0	275
72.0	300
78.0	325
84.0	350
90.0	375
96.0	400
102.0	425

P= 0.2

M	WSS IN MHZ
0.0	0
3.0	25
6.0	50
9.0	75
12.0	100
15.0	125
18.0	150
21.0	175
24.0	200
27.0	225
30.0	250
33.0	275
36.0	300
39.0	325
42.0	350
45.0	375
48.0	400
51.0	425

P= 0.3

M	WSS IN MHZ
0.0	0
2.0	25
4.0	50
6.0	75
8.0	100
10.0	125
12.0	150
14.0	175
16.0	200
18.0	225
20.0	250
22.0	275
24.0	300
26.0	325
28.0	350
30.0	375
32.0	400
34.0	425

P= 0.4

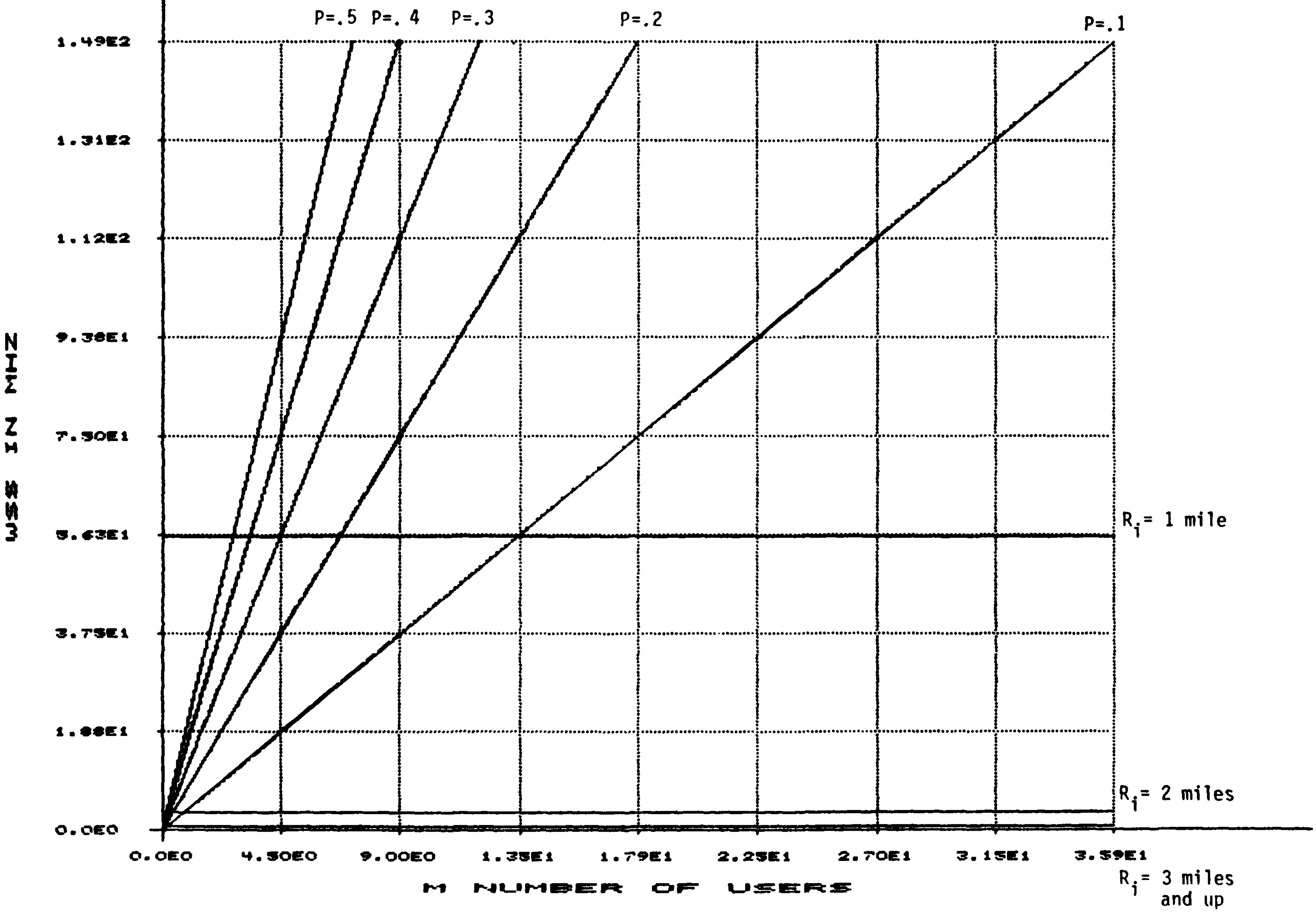
M	WSS IN MHZ
0.0	0
1.5	25
3.0	50
4.5	75
6.0	100
7.5	125
9.0	150
10.5	175
12.0	200
13.5	225
15.0	250
16.5	275
18.0	300
19.5	325
21.0	350
22.5	375
24.0	400
25.5	425

P= 0.5

M	WSS IN MHZ
0.0	0
1.2	25
2.4	50
3.6	75
4.8	100
6.0	125
7.2	150
8.4	175
9.6	200
10.8	225
12.0	250
13.2	275
14.4	300
15.6	325
16.8	350
18.0	375
19.2	400
20.4	425

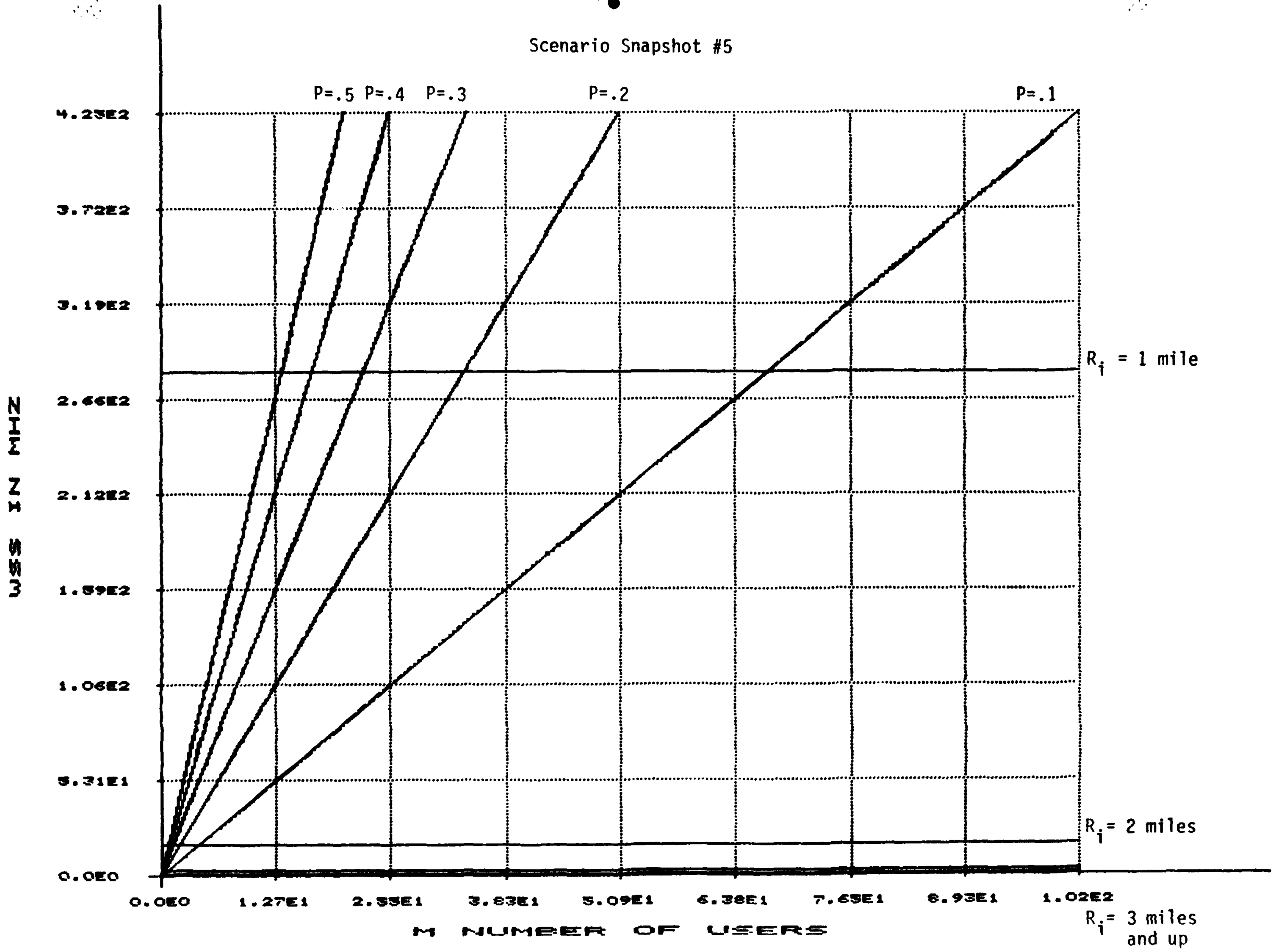
A1=1; A2=1 A3=.1; PT=10W; RI=1-5MI.

Scenario Snapshot #4



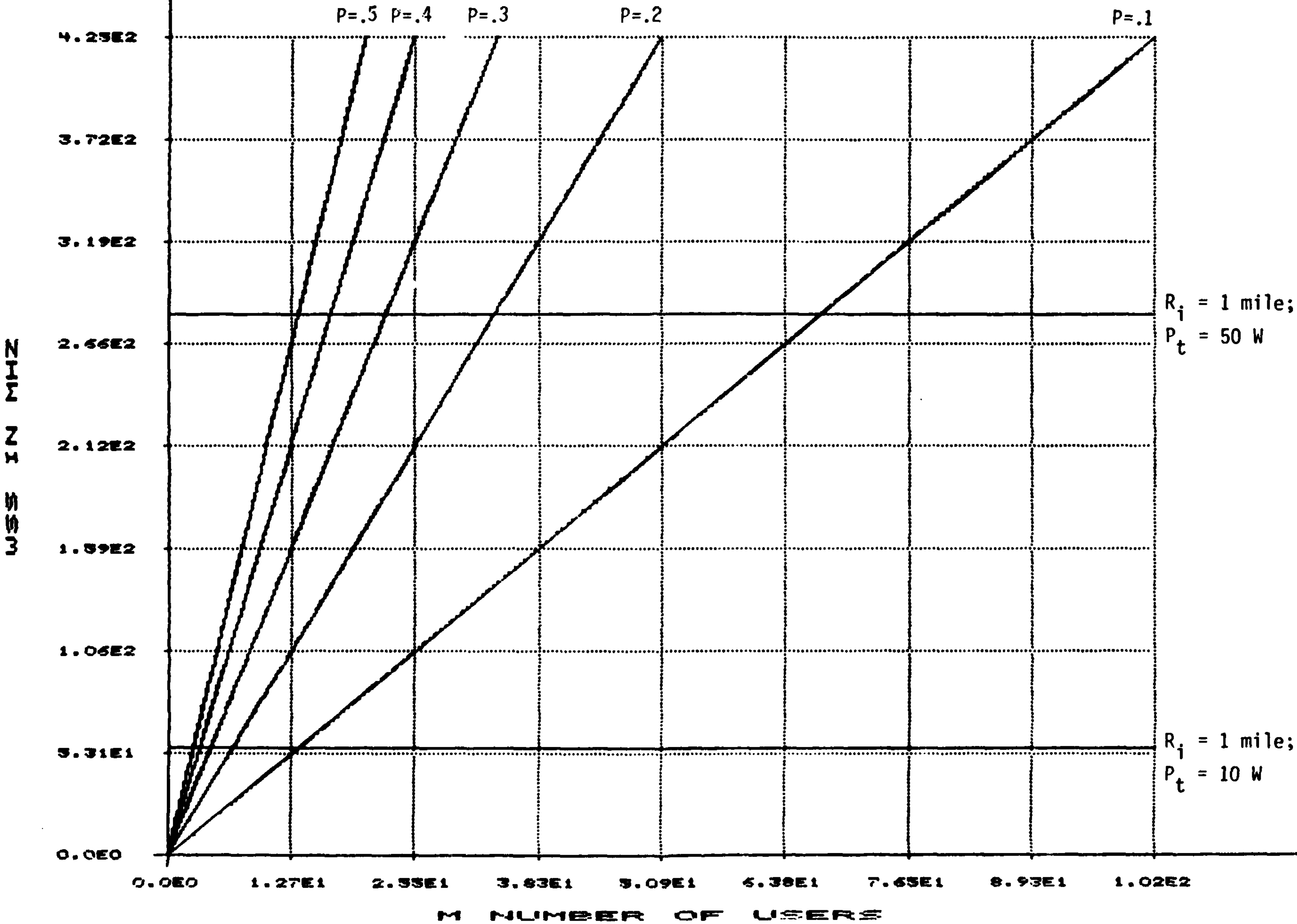
A1=1; A2=[illegible] A3=.1; PT=50W; RI=1-5MI.

Scenario Snapshot #5



A1=1; A2=1; A3=.1; PT=10,50W; RI=1MI.

Scenario Snapshot #6



SHOWING a_3 AS A DOMINATING FACTOR

SCENARIO SNAPSHOT #7

To Communicate,

$$W_{ss} \geq PM\, W_{bb} \left[\frac{5a_1^{\,4}}{3a_2\, a_3^{\,3}} \right] \qquad \text{from (13)}$$

letting

$a_1 = 1$ — a_1 = Characteristic Range of the Communication

$a_2 = 2$ — a_2 = Total Range of Operations

$a_3 = .3$ — a_3 = Range to Dominating Friendly Interferer

$W_{bb} = 25 \times 10^3$ Hz

therefore

$$W_{ss_{min}} = 771.6 \text{ PM MHz}$$

$$M = \frac{W_{ss_{min}}}{p\ 771.6} \qquad \text{(To Communicate)}$$

letting

$W_{ss_{min}}$ = 0 to 425 MHz in increments of 25 MHz , and

P = .1 to .5 in increments of .1

To Avoid Interception,

$$W_{ss} > \frac{P_t}{10^{-6.75} \; R_i^{\,4}} \qquad \text{from (14)}$$

letting

P_t = 10 Watts , and

R_i = 1 to 5 miles in increments of 1

It is worth noting that as the intercept range gets larger, the vertical lines gets closer to zero.

SCENARIO SNAPSHOT #8

The only difference between Scenario Snapshot #7 and #8 is the P_t in the equation To Avoid Interception. P_t equals 50 Watts.

SCENARIO SNAPSHOT #9

In this particular snapshot, snapshot #7 and #8 are combined to show that when one increases P_t to communicate without interception, a larger spread spectrum bandwidth, W_{ss}, is needed along with an increase in the number of users. R_i is shown at one mile only.

TO COMMUNICATE WITHIN R**4 PROPAGATION

A1= 1.0
A2= 2.0
A3= 0.3

P= 0.1

M	WSS IN MHZ
0.0	0
324.0	25
648.0	50
972.0	75
1296.0	100
1620.0	125
1944.0	150
2268.0	175
2592.0	200
2916.0	225
3240.0	250
3564.0	275
3888.0	300
4212.0	325
4536.0	350
4860.0	375
5184.0	400
5508.0	425

P= 0.2

M	WSS IN MHZ
0.0	0
162.0	25
324.0	50
486.0	75
648.0	100
810.0	125
972.0	150
1134.0	175
1296.0	200
1458.0	225
1620.0	250
1782.0	275
1944.0	300
2106.0	325
2268.0	350
2430.0	375
2592.0	400
2754.0	425

P= 0.3

M	WSS IN MHZ
0.0	0
108.0	25
216.0	50
324.0	75
432.0	100
540.0	125
648.0	150
756.0	175
864.0	200
972.0	225
1080.0	250
1188.0	275
1296.0	300
1404.0	325
1512.0	350
1620.0	375
1728.0	400
1836.0	425

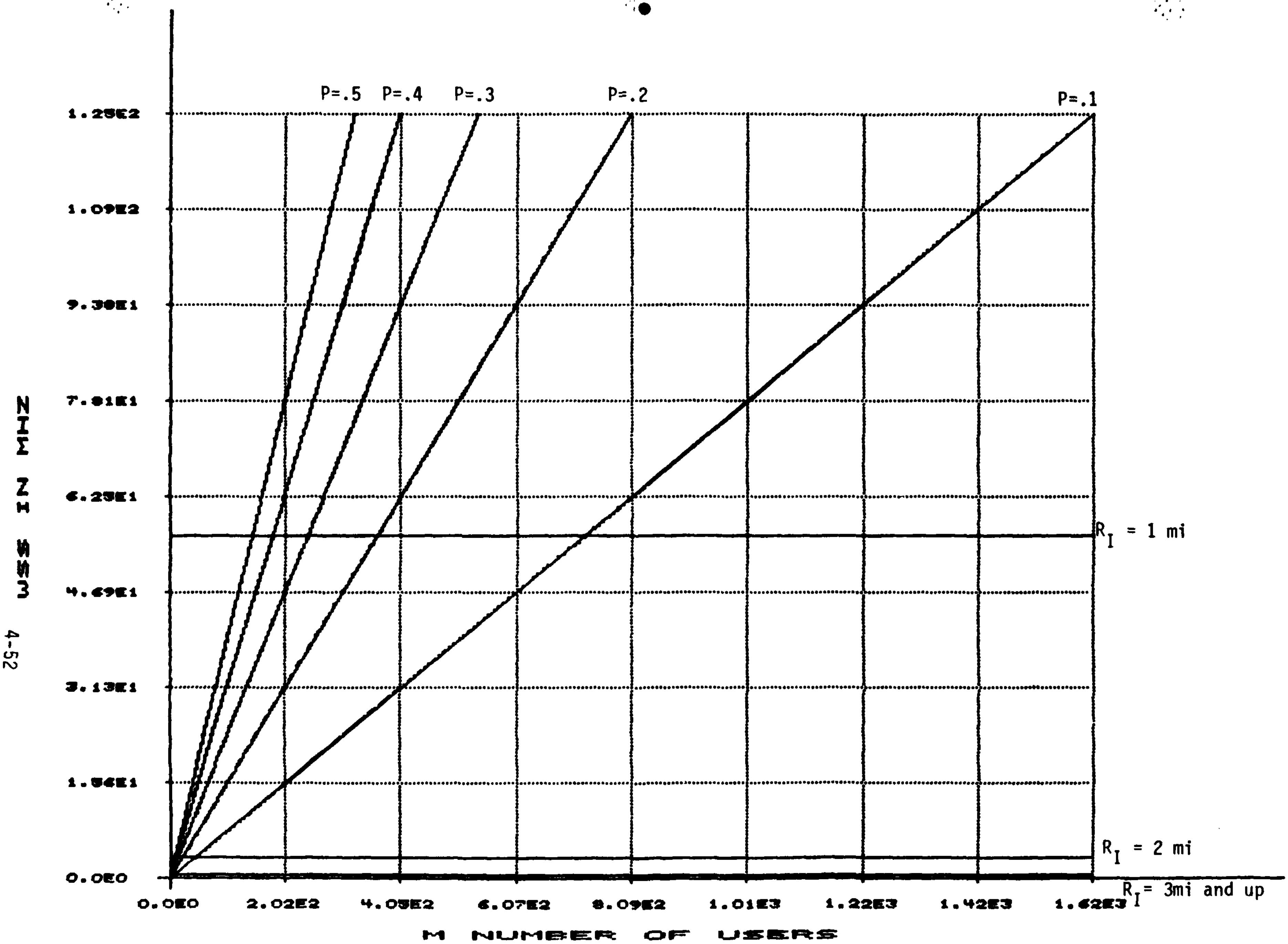
P= 0.4

M	WSS IN MHZ
0.0	0
81.0	25
162.0	50
243.0	75
324.0	100
405.0	125
486.0	150
567.0	175
648.0	200
729.0	225
810.0	250
891.0	275
972.0	300
1053.0	325
1134.0	350
1215.0	375
1296.0	400
1377.0	425

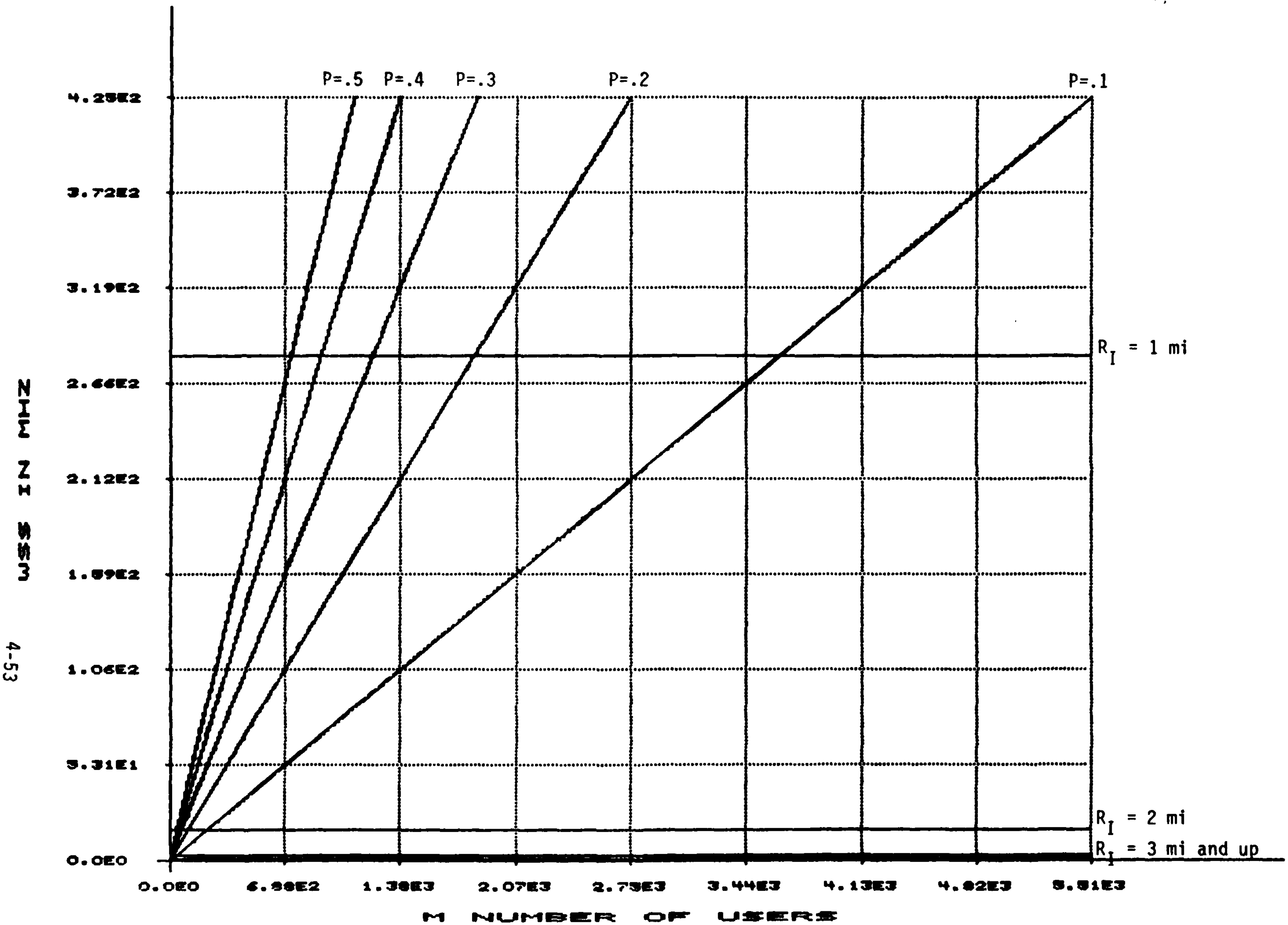
P= 0.5

M	WSS IN MHZ
0.0	0
64.8	25
129.6	50
194.4	75
259.2	100
324.0	125
388.8	150
453.6	175
518.4	200
583.2	225
648.0	250
712.8	275
777.6	300
842.4	325
907.2	350
972.0	375
1036.8	400
1101.6	425

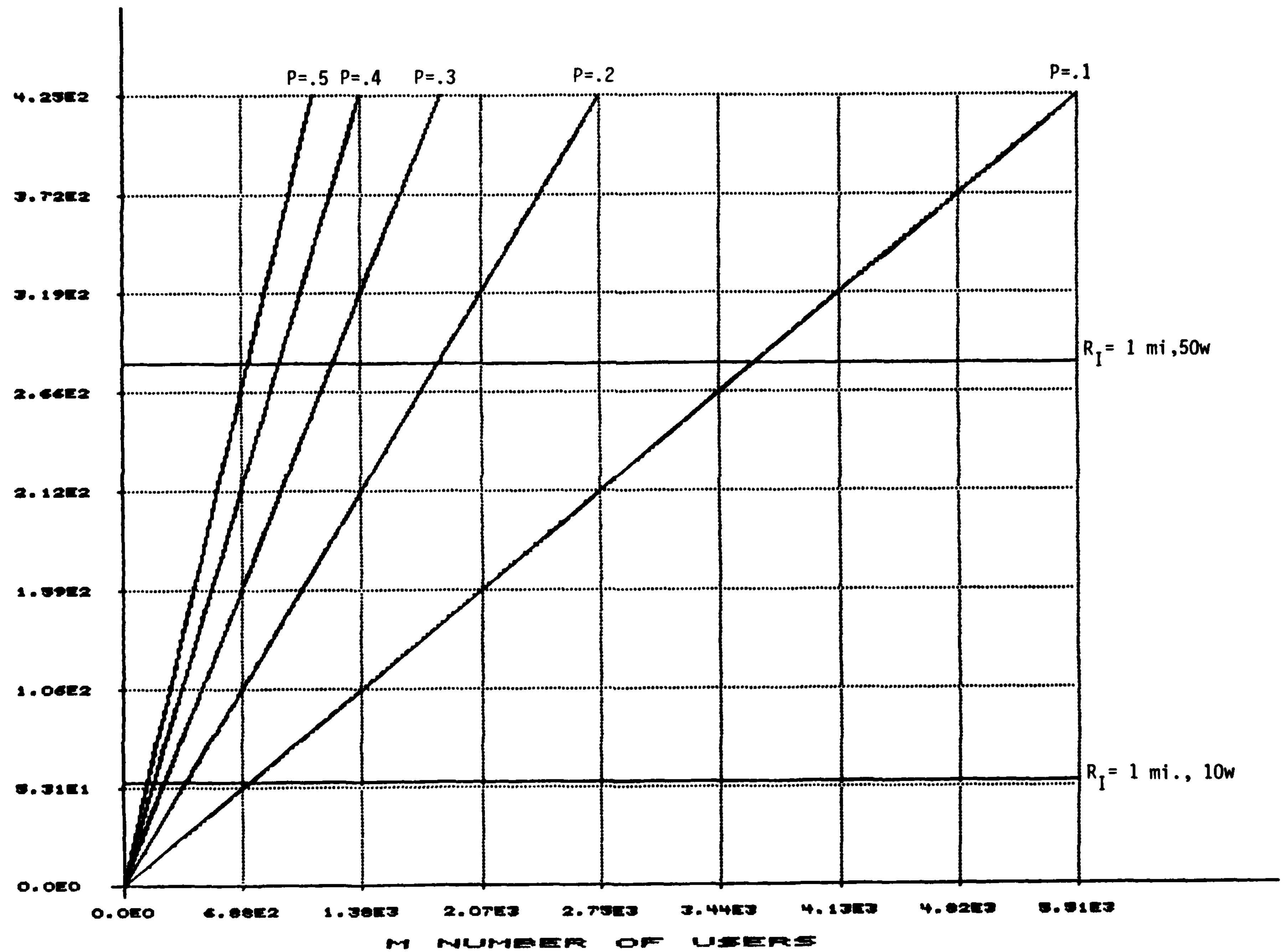
A1=1; A2=2; A3=.3; PT=10W; RI=1-5MI.



A1=1; A2=2; A3=.3; PT=50W; RI=1-5.



A1=1; A2=2; A3=.3; PT=10, 50W; RI=1MI.



4.4 AIR-TO-AIR INTERCEPTION

In air-to-air propagation, tranmissions are assumed to be line-of-sight and propagation losses are assumed to be due only to the $1/R^2$ spreading factor. In a network sense the airborne transceiver plays a key role in that it becomes the ground signal relay platform. Under the current effort emphasis was placed on the ground-to-ground and ground-to-air links and networks as the logical point-of-departure. It is strongly recommended that a thorough investigation of free-space line-of-sight propagation links and networks be the subject of future research.

5.0 Detectability Contours

A useful tool in the determination of the relative susceptibility of a communications signal to interception by a foreign receiver is the two-dimensional detectability contour. The detectability contour describes the loci of possible positions of a transmitter in the locale of an interceptor and receiver which possess an important common characteristic. In particular, the positions yield a constant, K, defined as the ratio of SNR at the input of the interceptor to SNR at the input of the intended receiver. This relationship assumes that the positioning of the receiver and interceptor, as well as pertinent transmission gain factors, remain constant. Therefore, the detectability contour defines all points where

$$\frac{(SNR)_I}{(SNR)_C} \equiv \frac{I}{C} = K \tag{1}$$

where K is a constant.
The constant K given in (1) is a function of pertinent gain factors of the three systems in question and propagation characteristics of the communications signal. Pertinent gain factors include the antenna gains of the receiver and interceptor relative to the transmitter, front end losses and noise levels at both the receiver and interceptor, and a signal suppression factor related to the LPI protection of the communication signal.

5.1 Analysis of Free Space Propagation

For the case when both the communication path and the intercept path are free space propagation the analysis is straight forward and can be readily performed by hand as was previously exhibited in the proposal. (See Appendix C). The simplicity of this analysis lies in the circular geometry exhibited by the contours. In this case, only two parameters, the center and radius, are needed to completely define the contour.

5.2 Analysis of Ground-to-Ground Communications

When the communication path exhibits $(1/R^4)$ characteristics typical of

ground-to-ground communications the detectability contours no longer exhibit the simple circular shape found for $1/R^2$ situation. This can be seen by substituting $R_C{}^4$ for $R_C{}^2$ in the equations of Appendix C yielding

$$\frac{(SNR)_I}{(SNR)_C} \equiv \frac{I}{C} = M\frac{R_C{}^4}{R_I{}^2} = M\left[\frac{(x+a/2)^2+y^2}{(x-a/2)^2+y^2}\right]^2 \tag{2}$$

where M and a remain unchanged from Appendix C. Equation (2) can be written equivalently as

$$M[x^2+ax+a^2/4+y^2]^2 = \frac{I}{C}\,[x^2-ax+a^2/4+y^2] \tag{3}$$

Solving for contour points which are solutions to (3) is a task most easily accomplished through computer analysis. In order to facilitate such an analysis (3) is rewritten in polar coordinate form yielding

$$M[R^2+aR\cos\Theta+a^2/4]^2 = \frac{I}{C}\,[R^2-aR\cos\Theta+a^2/4] \tag{4}$$

where $\quad R\equiv\sqrt{x^2+y^2} \qquad 0\leq\ \Theta\ \leq 2\pi$

$x=R\cos\Theta \quad y=R\sin\Theta$

Expanding the left side of (4) and manipulating yields a fourth order polynomial in R

$$R^4+A_3R^3+A_2R^2+A_1R+A_o=0 \tag{5}$$

where
$$\begin{aligned}
A_3 &= 2a\cos\Theta\\
A_2 &= a^2/2 + a^2\cos^2\Theta-(\tfrac{I}{C})\cdot(\tfrac{1}{M})\\
A_1 &= a^3/2\cos\Theta+a(\tfrac{I}{C})(\tfrac{1}{M})\cos\Theta\\
A_o &= a^4/16-a^2/4\ (\tfrac{I}{C})(\tfrac{1}{M})
\end{aligned}$$

Note the importance of the factor $(\frac{I}{C})\cdot\frac{1}{M}$ in determining the detectability

contour. The locus of points defining the contour is now readily found by rotating through its range of values and solving for values of R which solve (4) for specific values of $(\frac{I}{C}) \cdot \frac{1}{M}$ and a. A program was implemented to perform this task and the resulting data is plotted in figures (5-1 thru 5-3) for three values of $(\frac{I}{C}) \cdot \frac{1}{M}$ and a chosen distance from receiver to interceptor. Although the contours no longer exhibit the circular geometry of the free space propagation case, symmetry remains about the reference x-axis. This symmetry obviously results from the fact that for each point in the first or second quandrants there exists a corresponding point in the third or fourth quadrants with identical positioning relative to the interceptor and receiver.

A two way communications link can be employed for the purpose of controlling the signal strength at the receiver. In this case, the receiver SNR is approximately a constant value regardless of the location of the transmitter. Then the detectability contours define the locus of points where

$$\frac{(SNR)_I}{(SNR)_{C_o}} = K \quad \text{or} \quad (SNR)_I = K\ (SNR)_{C_o} \tag{6}$$

Therefore, when this situation occurs the detectability contours also define transmitter locations which provide the interceptor with a constant SNR.

Obviously, in order for the detectability contour concept to be of particular use to a communicator, he must have acquired information pertaining to the location (i.e. range and bearing) of some interceptor. Otherwise, any approximated contour will be incorrect in size and/or orientation. When range and bearing information are available then a computer program could be implemented to determine the approximate contour upon which the transmitter is located. When this is accomplished the SNR at the interceptor can easily be determined which in turn approximates his ability to correctly intercept the transmission. Furthermore, if it is determined that the interception may in fact have the SNR necessary to intercept signal transmission, the detectability contours can help dictate actions which may be taken to reduce interceptor performance. The most efficient means of reducing interceptor SNR without adversely affecting the intended reception is by manipulation of the parameters which constitute K in (6). This can be accomplished by alternating antenna gains in the direction of the interceptor while maintaining other

Figure 5-1

DETECTABILITY CONTOUR

$(\frac{I}{C}) \cdot \frac{1}{M} = 0.1$

GROUND-TO-GROUND $(1/R^4)$ PROPAGATION

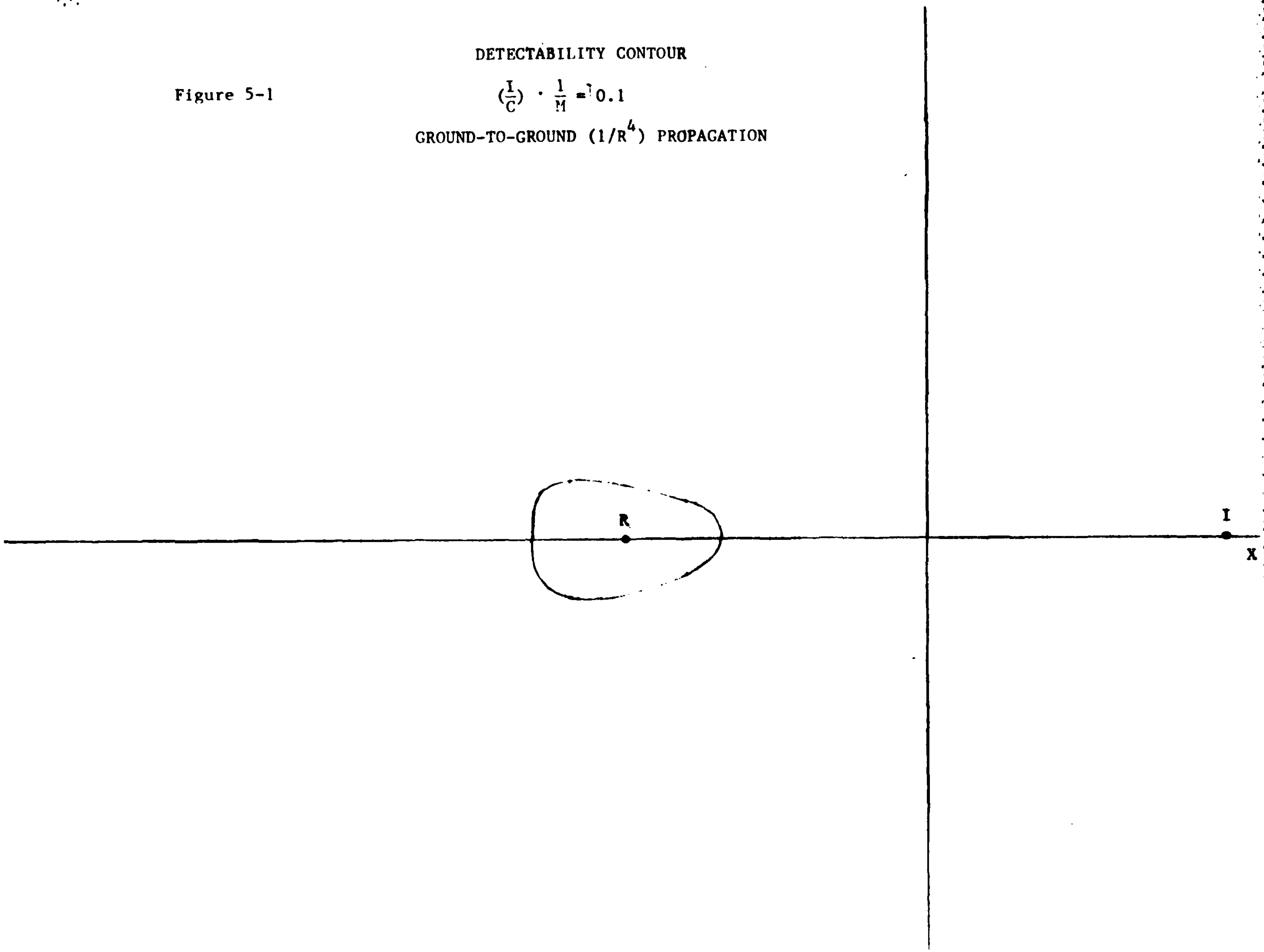


Figure 5-2

DETECTABILITY CONTOUR

$(\frac{I}{C}) \cdot \frac{1}{M} = 1.0$

GROUND-TO-GROUND $(1/R^4)$ PROPAGATION

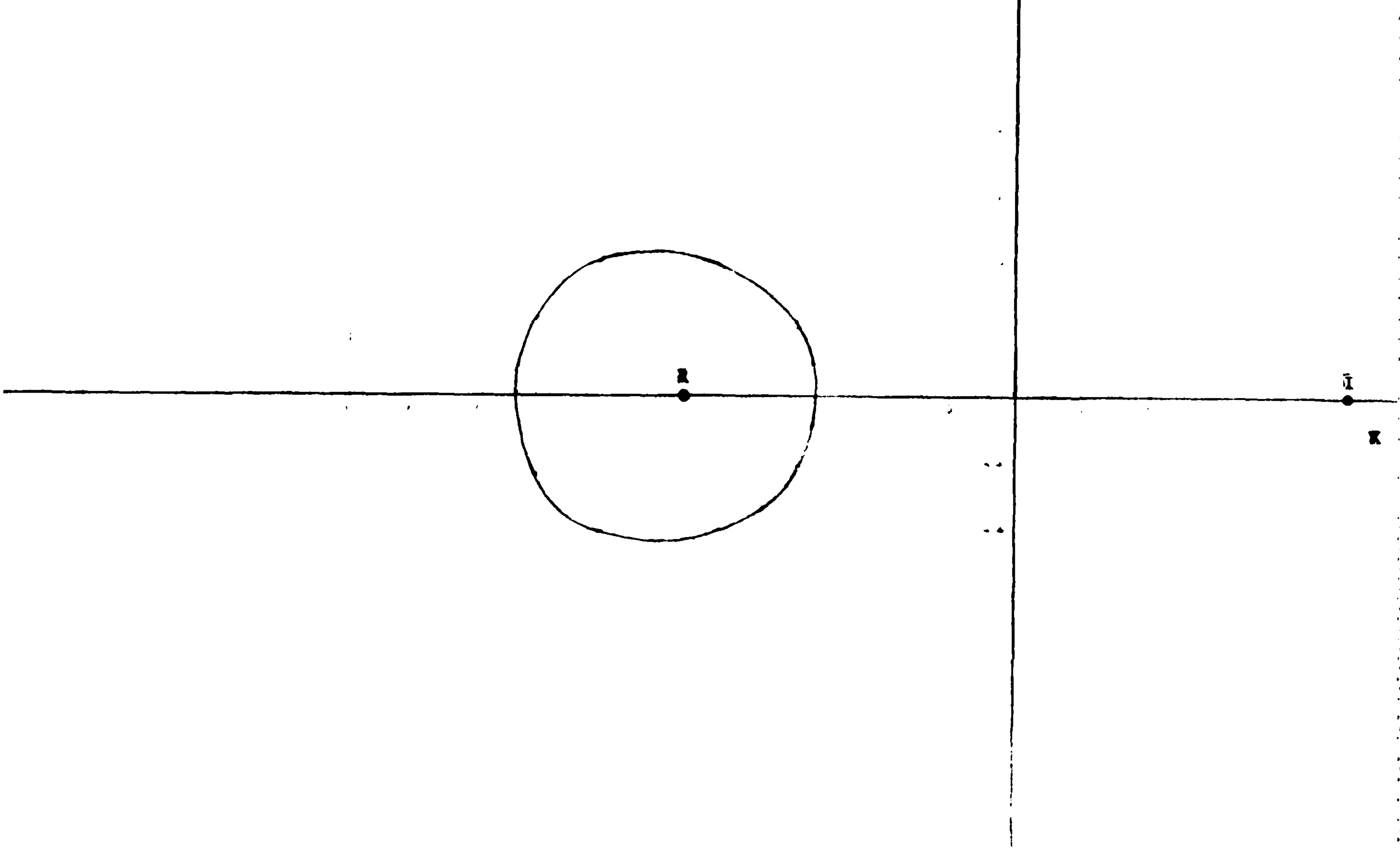
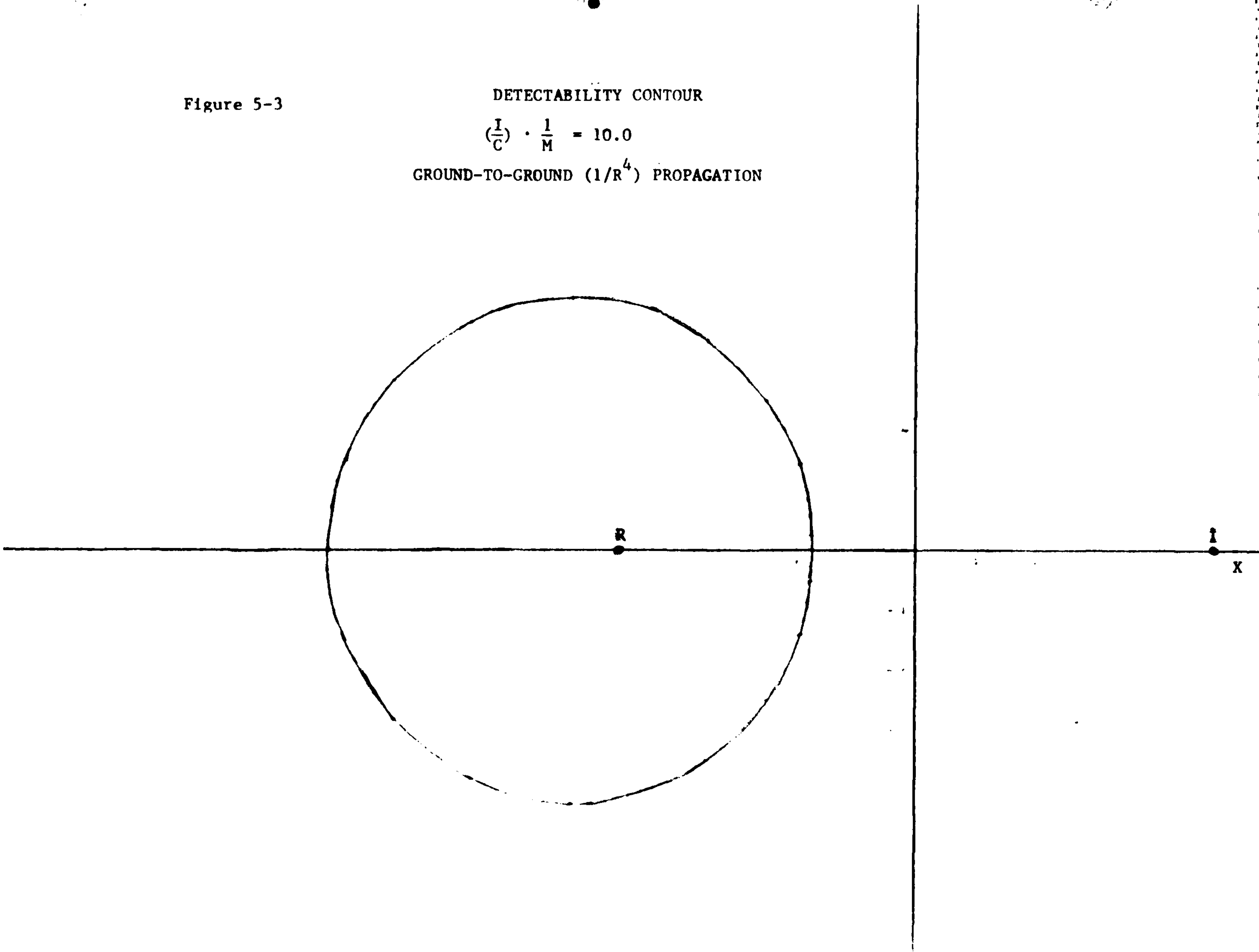


Figure 5-3

DETECTABILITY CONTOUR

$$\left(\frac{I}{C}\right) \cdot \frac{1}{M} = 10.0$$

GROUND-TO-GROUND ($1/R^4$) PROPAGATION



parameters as constants thereby maintaining the SNR at the receiver. This effectively places the transmitter on a new detectability contour. The same result can be attained by reducing the signal suppression factor through the implementation of some LPI technique. If manipulation of such parameters is unattainable, then at the very least, if transmitter mobility is available, the detectability contours can provide transmitter locations which will permit secure operation.

Problems with the contour concept arise in calculating certain parameters within the above expressions. In particular, the gain of the interceptor's antenna in the direction of the transmitter may not be available nor may the signal suppression factor, which may vary with particular interceptor systems. Therefore, a somewhat significant amount of information pertaining to the location and particular characteristics of the interceptor must be known for detectability contour analysis to be effective. However, when this information is available or reasonably estimated, the contour concept can be very useful.

6.0 Limits to Parameter Variation

There are practical limits to how much parameter variation is permitted by the tactical situation in which spread spectrum communication systems are operated. Figure 6.1 identifies the network architecture necessary to achieve Low-Probability-of-Intercept. At the link level one can identify transmitter and receiver parameters which are constrained by the reality of the tactical situation. Network methods, likewise, are also constrained by practical limits. This section addresses these limits in a qualitative way.

6.1 LINK LEVEL LIMITS IMPOSED BY MOBILITY AND CONCEALMENT

6.1.1 Mobility Limits on the Link

The requirement for mobility in tactical environments goes hand-in-hand with the goal of survivability which is paramount in the defensive game plan of all military forces. As such, constraints on size, weight, space and power required, set-up and tear-down times, timing, etc. are placed on the tactical system.

These link constraints severely affect the antenna subsystem. Element size, array aperture, directivity, set-up and tear-down times, etc. are all adversely limited by the tactical situation.

Power requirements must also be considered in light of the tactical situation as effective radiated power (ERP) is bounded by antenna gains and the power supply available in the tactical system.

Other considerations closely tied to mobility are the ruggedness and endurance of the system under hostile conditions. This issue causes a tradeoff to be made between the mean time between failures (MTBF) of the system components and the number of spares required to be transported with the system.

6.1.2 Concealment Limits on the Link

The tactical requirement for system link concealment has been studied from the viewpoint that electromagnetically the link must maintain a low profile. Should its signature be unique or distinct from that of other communication systems operating in the same general area, then it becomes a red flag. (An unique signature is used in SIGINT operations for templating and determination of the order of battle of opposing forces). Use of DSE spread spectrum provides a level of covertness if the signal is intentionally transmitted with a power spectral density at or below the noise level. FH spread spectrum will provide a level of anti-jam protection but its electromagnetic signature is far from being covert (or LPI).

Physical concealment of the system from visual observation places an added burden on the communication system developer to use small indiscernable components (i.e., antennas, generators, shelter, etc.).

6.1.3 Mobility Limits on the Network

Tactical constraints on the network are most stringent when nodes/relays are required to operate while in motion (i.e. on board helicopters, airplanes, ships, and moving ground vehicles).

Due to encoding techniques, interleaving and digital processing in general, timing is a critical issue. Mobility of one or more terminals/relays within the network introduces the need for strong code search, acquisition and tracking schemes as well as three dimensional spatial search. The effects of doppler shift, multipath propagation, masking, etc. tend to limit the data rates, duty cycles, and directivity achievable while they increase the power, dynamic routing, and adaptive processing requirements needed for reliable operation.

6.1.4 Concealment Limits on the Network

Concealing entire networks of radios in a tactical situation is probably the most difficult task facing a communication system designer. The limitations placed on the system include those previously mentioned plus additional requirements which, if not adhered to, will give away information about other network nodes. These requirements could involve encryption of data, protocol restrictions, transmit power/data rate restrictions, etc.

Figure 6.1 NETWORK ARCHITECTURE TO ACHIEVE LPI

<u>LINK METHODS (Technical Means)</u>

- Transmitter
  - Source Encoding
  - Interleaving
  - Channel Encoding
  - Spread Spectrum
  - Power Control
  - Antenna Directivity
  - Low Duty Cycle
  - Uniform Transmissions
- Receiver
  - Coordinate Power Control
  - Antenna Directivity
  - Adaptive Processing
  - Low Noise Figure

<u>NETWORK METHODS (Technical Means)</u>

- Choice of Relay Sites
- Propagation Mode
- Frequency Selection
- Message Acknowledgements
- Mobility and Concealment
- Antenna Directivity, Perhaps Adaptive Beam Steering
- Decoys and Masking
- Dynamic Routing

7.0 FUTURE OBJECTIVES AND RECOMMENDATIONS

7.1 OBJECTIVES

The current effort is considered to be a significant contribution toward the U.S. Army's goal of developing adaptive spread spectrum network transceivers. The analysis, modelling and snapshots developed thus far are considered to be a beginning, but much is left to be done before hardware can be implemented. A long term plan is envisioned to achieve the ultimate goals. It entails analysis of the tactical battlefield environment to include both Red and Blue forces. Areas for further investigation include analysis of the effects an intercepter's own communication assets would have on his performance, the effects of adding both Red and Blue Force Jammers to the scenario, establishing and quantifying figures of confidence on the intercepter and communicator performance, and wideband signal propagation modelling which could be used to replace the narrowband ITM currently being utilized for determination of excess losses along the propagation path. Appendix D is included as an introduction to methods which may be employed to produce confidence figures.

The interaction between controllable parameters of a Direct Sequence Encoded (DSE) Spread Spectrum system has been determined to be a multiobjective problem in resource allocation. The ultimate goal of optimizing key controllable parameters to achieve LPI for a communication network involved the analysis of each parameter and determination of interactions between them. Optimization of these key parameters presents intermediate goals which are conflicting in nature and in trying to satisfy them simultaneously, it is no longer clear what could be described as an "optimal" solution. The inclusion of objective vectors in n-dimensional space therefore will introduce new modelling and mathematical approaches to DSE spread spectrum radio networking, and thus, the notion of an optimal solution will no longer be

applicable. Instead, the concept of a set of non-dominated solutions may be introduced to the problem definition.

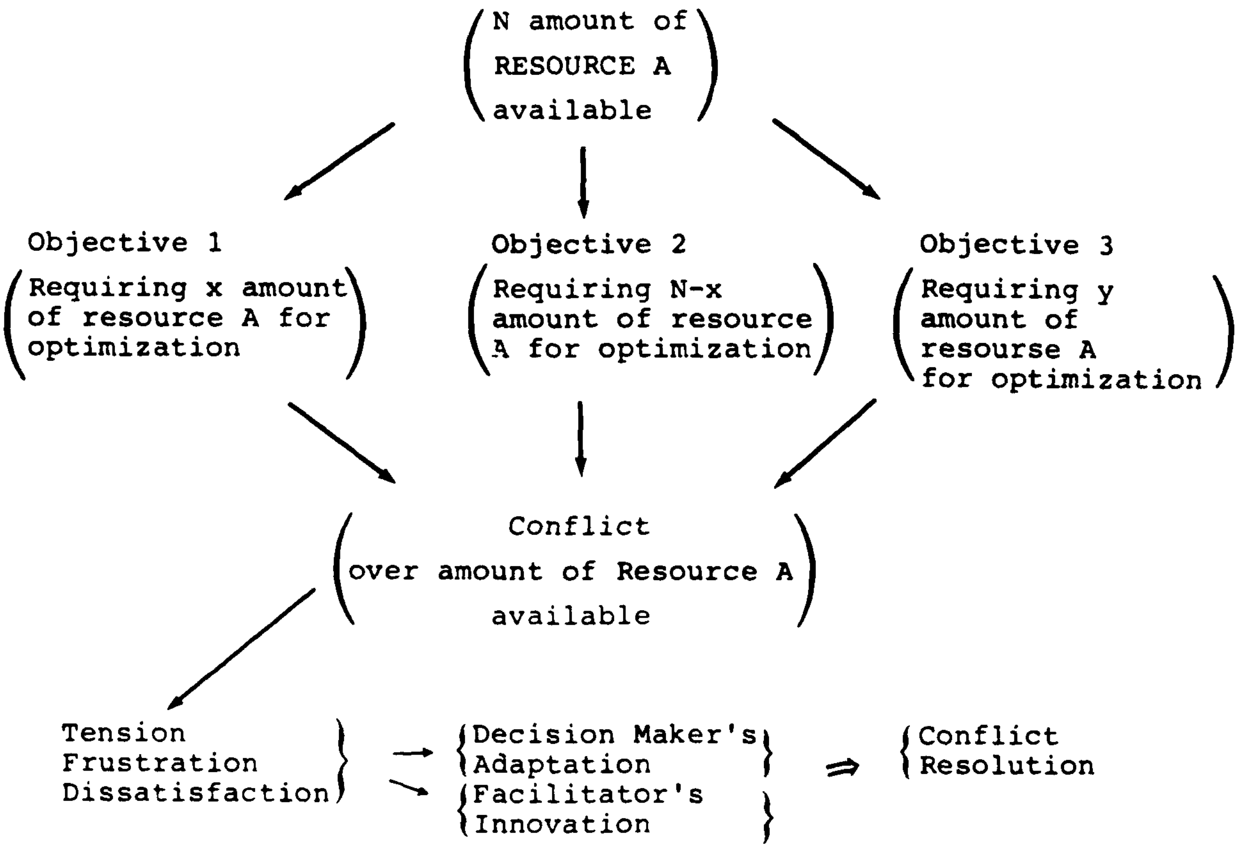
A number of methods have been developed over the last decade which allow one to deal with multiobjective problems in a formal manner. The structural elements used by these methods have originated in the areas of mathematical programming, utility theory, probability and statistics, managerial accounting and decision theory.

Mathematical programming can be used as the main vehicle for integrating the controllable parameters for DSE networking (which involves an infinite number of alternatives). As the concept of an "optimal solution" was determined not to apply here, the concept of a "satisfactory solution" or satisfactum may be examined. Our definition of the satisfactum is any value within an interval of acceptable solutions.

Figure 7.1 shows the generic process by which conflict between objectives competing for the same resource may be resolved.

7.2 RECOMMENDATIONS

It is strongly recommended that, as a minimum, the work outlined in section 7.1 be the subject of future research and that close interaction with government personnel familiar with the tactical battlefield of today be initiated. Modelling of the tactical environment and interactive software development with government researchers will lend much to the viability and utility of the model being developed.



Post Decision Functions

Chosen alternative decision attractiveness is enhanced.
Rejected alternative decision attractiveness is enhanced.

Figure 7-1. Conflict Resolution

8.0 REFERENCES

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APPENDIX A

SPREAD SPECTRUM MODULATION AND ANTENNA DIRECTIVITY IN LPI DESIGN

INTRODUCTION

Three issues critical to the design of military, LPI communication systems are power transmitted, spread spectrum modulation and transmitter antenna directivity and pattern. This analysis initially considers the tradeoff between the use of spread spectrum modulation and antenna directivity to achieve LPI in military communications and then extends these results to the case where power control is used by the communicators.

ANALYSIS OF SPREAD SPECTRUM AND ANTENNA GAIN

The usual triangle formed by the communication transmitter (T) , communication receiver (R) and intercept receiver (I) is shown in Figure A 1.

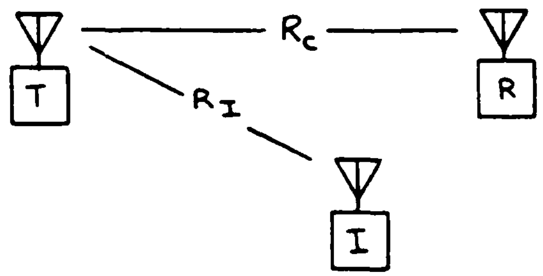

Figure A1.. Interceptor - Communications Triangle

If propagation along the communication and intercept paths is assumed lossless with attenuation proportional to $1/R^{\ell}$ (where ℓ typically equals 2 or 4), it is straightforward to write expressions which determine the power of the transmitted communication signal at the communication receiver, S , and the power of the transmitted signal received at the intercept receiver, Q . These expressions are as follows:

$$S = \frac{P_T G_{TR} G_{RT} \lambda^2}{(4\pi R_c)^2 L_R} \quad \frac{K_c}{R_c^{\ell_c}} \qquad (1)$$

where

K_c = Constant of Attenuation; Unity for $1/R^2$,

P_T = Transmitted Communication Power,

G_{TR} = Transmitter Antenna Gain in Direction of Communication Receiver (relative to omni),

G_{RT} = Communication Receiver Gain in Direction of Transmitter (relative to omni),

λ = Wavelength of Center Frequency of Communication Signal,

R_c = Communication Distance,

ℓ_c = Attenuation Exponent on Communication Path,

L_R = Loss at Communication Receiver, and

$$Q = \frac{P_T G_{TI} G_{IT} \lambda^2}{(4\pi R_I)^2 L_I} \quad \frac{K_I}{R_I^{\ell_I}} \qquad (2)$$

where

K_I = Constant of Attenuation; Unity for $1/R^2$,

G_{TI} = Transmitter Antenna Gain in Direction of Intercept Receiver (relative to omni),

G_{IT} = Intercept Receiver Antenna Gain in Direction of Transmitter (relative to omni),

R_I = Intercept Range,

ℓ_I = Attenuation Exponent on Intercept Path,

L_I = Loss at Intercept Receiver.

The power, S , received at the communication receiver equals the product of the received energy per bit, E_b , and W_{SS} , the information rate which roughly equals the baseband bandwidth of the communication receiver. Denoting the communication receiver thermal noise power spectral density by N_{oc}, the received E_b/N_{oc} can be written from (1) in the form

$$\frac{E_b}{N_{oc}} = \frac{P_T G_{TR} G_{RT} \lambda^2}{N_{oc} W_{BB} (4\pi)^2 L_c} \frac{K_c}{R_c^{2+\ell_c}} \tag{3}$$

Assume that channel encoding and diversity leads to the requirement that E_b/N_{oc} have a value not less than $(E_b/N_{oc})_m$. Then the maximum communication range, $R_{c,M}$ can be expressed using (3) as

$$R_{c,M}^{2+\ell_c} = \frac{P_T G_{TR} G_{RT} \lambda^2 K_c}{N_{oc} W_{BB} (4\pi)^2 L_c (E_b/N_{oc})_m} \tag{4}$$

Now consider the capability of the interceptor. For generality assume that the intercept receiver is non-linear having a Signal-to-Noise-Ratio (SNR) at the point of detection given by

$$(SNR)_o = \frac{\beta (SNR)_{IN}^2 T_I W_{SS}}{1 + \frac{\beta}{\alpha} (SNR)_{IN}} \tag{5}$$

Where T_I is the integration time of the radiometer-type receiver, W_{SS} is the intercept receiver RF bandwidth assumed equal to the total specturm in which the communication may be found, α and β are constants depending on details of the detection receiver and

$$(SNR)_{IN} = \frac{Q}{N_{OI} W_{SS}} \tag{6}$$

where N_{OI} is the thermal noise power spectral density of the intercept receiver. Using (4) to solve for P_T and then substituting (2) into (6) yields

$$(SNR)_{IN} = \frac{R_{C,M}^{2+\ell_C}}{R_I^{2+\ell_I}} \left[\left(\frac{E_b}{N_{OC}} \right)_m \frac{G_{TI}\, G_{IT}\, N_{OC}\, L_C\, K_I}{G_{TR}\, G_{RT}\, N_{OI}\, L_I\, K_C} \right] \frac{W_{BB}}{W_{SS}} \tag{7}$$

$$\equiv H \frac{R_{C,M}^{2+\ell_C}}{R_I^{2+\ell_I}} \quad \frac{W_{BB}}{W_{SS}}$$

where for convenience H is defined as the term in brackets in (7). Equation (5) can be solved for $(SNR)_{IN}$ yielding the one reasonable root given by

$$(SNR)_{IN} = \frac{1 + \sqrt{1 + \dfrac{4 T_I W_{SS} \alpha^2}{\beta (SNR)_o}}}{\dfrac{2 T_I W_{SS} \alpha}{(SNR)_o}} \tag{8}$$

Using (8) in (7) yields

$$R_I^{2+\ell_I} = R_{C,M}^{2+\ell_C} \, H \, \frac{W_{BB}}{W_{SS}} \quad \frac{\dfrac{2 T_I W_{SS} \alpha}{(SNR)_o}}{1 + \sqrt{1 + \dfrac{4 T_I W_{SS} \alpha^2}{\beta (SNR)_o}}} \tag{9}$$

Denoting the minimum interceptor SNR as $(SNR)_{o,m}$, (9) yields the maximum intercept range, $R_{I,M}$ as

$$R_{I,M}^{2+\ell_I} = R_{C,M}^{2+\ell_C} \, H \, \frac{W_{BB}}{W_{SS}} \quad \frac{\dfrac{2 T_I W_{SS} \alpha}{(SNR)_{o,m}}}{1 + \sqrt{1 + \dfrac{4 T_I W_{SS} \alpha^2}{\beta (SNR)_{o,m}}}} \tag{10}$$

This general expression describes the intercept range as it depends on propagation modes (through ℓ_I and ℓ_c), the maximum communication range ($R_{C,M}$), the communication baseband modulatior and error control (through $(E_b/N_{oc})_m$), the antenna gain (through H) and the spread spectrum modulation through the remaining terms in (10).

From the quadratic term in (10), the dependence of the maximum intercept range on the spread spectrum bandwidth depends on the value of time - bandwidth product ($T_I W_{SS}$) achieved at the interceptor. The critical value is given by

$$(T_I W_{SS})_o = \frac{\beta (SNR)_{o,m}}{4\alpha^2} \tag{11}$$

When $T_I W_{SS} >> (T_I W_{SS})_o$, (10) becomes

$$R_{I,M,S}^{2+\ell_I} = R_{C,M}^{2+\ell_C} H \frac{W_{BB}}{W_{SS}} \sqrt{\frac{\beta (T_I W_{SS})_L}{(SNR)_{o,m}}} \tag{12}$$

where $(T_I W_{SS})_L$ denotes that $T_I W_{SS}$ is large. This corresponds to $(SNR)_{IN}$ being small resulting in quadratic receiver behavior in which $(SNR)_o = \beta (SNR)_{IN}^2 (T_I W_{SS})_L$. When $1 \leq T_I W_{SS} << (T_I W_{SS})_o$, (10) becomes

$$R_{I,M,L}^{2+\ell_I} = R_{C,M}^{2+\ell_C} H \frac{W_{BB}}{W_{SS}} \frac{\alpha (T_I W_{SS})_S}{(SNR)_{o,m}} \tag{13}$$

where $(T_I W_{SS})_s$ denotes that $T_I W_{SS}$ is small. This corresponds to $(SNR)_{IN}$ being large resulting in linear receiver behavior in which $(SNR)_o = \alpha\,(SNR)_{IN}\,(T_I W_{SS})_s$.

When the spread spectrum, LPI signal design limits the intercept integration time to the special value

$$T_{Io} = \frac{\beta (SNR)_{o,m}}{4\alpha^2 W_{SS}} \tag{14}$$

the maximum intercept range is given by

$$R_{I,M}^{2+\ell_I} = R_{C,M}^{2+\ell_C}\, H\, \frac{W_{BB}}{W_{SS}}\, \frac{\frac{\beta}{2\alpha}}{1+\sqrt{2}} \tag{15}$$

Since the minimum reasonable value of $(T_I W_{SS})_s$ is unity, (13) yields the minumum, maximum intercept range

$$R_{I,\min Max}^{2+\ell_I} = R_{C,M}^{2+\ell_C}\, H\, \frac{W_{BB}}{W_{SS}}\, \frac{\alpha}{(SNR)_{o,m}} \tag{16}$$

This is the intercept range for the minimum integration time of $1/W_{SS}$.

Using (16) in (12), yields the maximum intercept range for quadratic intercept performance for larger values of $T_I W_{SS}$

$$R_{I,M,S} = R_{I,\min Max}\left[\frac{\beta (SNR)_{o,m}\,(T_I W_{SS})_L}{\alpha^2}\right]^{\frac{1}{2(2+\ell_I)}} \tag{17}$$

From (17), it is apparent that the maximum intercept range for small values of $(SNR)_{IN}$ is potentially considerably larger than the intercept range for large values of $(SNR)_{IN}$.

ANALYSIS OF POWER CONTROL

From (3) the communication receiver achieves a value of energy-per-bit-per-noise-power-spectral-density equal to

$$\frac{E_b}{N_{oc}} = \frac{P_T}{R_c^{2+\ell_c}} \quad \frac{G_{TR}\, G_{RT}\, \lambda^2\, K_c}{W_{BB}\, (4\pi)^2\, L_c} \tag{18}$$

Now suppose that the transmitted power at the communication transmitter ($P_T(R_c)$) is controlled such that out to the maximum communication range, $R_{c,M}$, the value of E_b/N_{oc} remains constant at $(E_b/N_{oc})_m$. This requires that

$$\left(\frac{E_b}{N_{oc}}\right)_m = \frac{P_T(R_c)}{R_c^{2+\ell_c}} \quad \frac{G_{TR}\, G_{RT}\, \lambda^2\, K_c}{W_{BB}\, (4\pi)^2\, L_c} \tag{19}$$

Comparing (19) and (4) yields

$$P_T(R_c) = P_T \frac{R_c^{2+\ell_c}}{R_{c,M}^{2+\ell_c}} \tag{20}$$

which assumes there are no obstacles to propagation not accounted for by the propagation model.

Under power control, the communication receiver receives the minimum required E_b/N_{oc} at all ranges, not just at the maximum communication range. Hence, when the communicators use power control, the intercept range depends on the actual communication range - not the maximum communication range. In particular for

power controlled communications as defined by (19), (10) becomes

$$R_{I,M}^{2+\ell_I} = R_c^{2+\ell_c} H \frac{W_{BB}}{W_{SS}} \frac{\dfrac{2T_I W_{SS} \alpha}{(SNR)_{o,m}}}{1 + \sqrt{1 + \dfrac{4T_I W_{SS} \alpha^2}{\beta (SNR)_{o,m}}}} . \qquad (21)$$

Likewise equations (12), (13), (15) and (16) can be rewritten substituting the actual communication range, Rc, for the maximum communication range, $R_{C,M}$.

When power control is used it is a simple matter to derive contours in two spatial dimensions of constant integration time needed to achieve a certain value of $(SNR)_o$ for the case when all propagation is free space; i.e., $\ell_I = \ell_C = 0$. For other cases, these contours have yet to be reported in the open literature.

DISCUSSION

From (12), we see that for the desired case from the point of view of the LPI signal designer, i.e. $(SNR)_{IN} \ll 1$, an increase in spread spectrum bandwidth (W_{SS}) results in less reduction in the intercept range than an equal increase in the antenna gain (G_{TR}). A radiometer may permit intercept at greater ranges than linear receivers.

From (15), when the interceptor integration time T_I is restricted to T_{Io} as given by (14), increases in the spread spectrum bandwidth (W_{SS}) and the antenna gain (G_{TR}) have the same impact on the intercept range.

From (13), when $(SNR)_{IN} \gg 1$, since $T_I \cong 1/W_{SS}$, increases in the spread spectrum modulation bandwidth, W_{SS} , and the antenna gain (G_{TR}) have the same impact on the intercept range.

Generally speaking, a change in antenna directivity by a certain factor results in at least as much reduction in intercept range as achieved by an increase in spread spectrum bandwidth by the same factor. This of course assumes that the intercept receiver is not in the main lobe of the transmit antenna.

APPENDIX B

LIST OF TABULAR DATA

APPENDIX B

LIST OF TABULAR DATA

TABULAR DATA FOR AIR-TO-GROUND INTERCEPT

PERFORMANCE AS A FUNCTION OF TRANSMITTER ANTENNA GAIN

(for Figure 3.2.a)

```
TRANSMITTER ANTENNA HEIGHT =   10.00 FT
TRANSMITTER ERP =   100.00 Watts
COMMUNICATION RECEIVER LOSS =     2.00 dB
COMMUNICATION RECEIVER ANTENNA GAIN IN THE DIRECTION OF THE TRANSMITTER =    3.00
COMMUNICATION RECEIVER ANTENNA HEIGHT =   10.00 FT
INTERCEPT RECEIVER ANTENNA HEIGHT =   60.00 FT
SNR REQUIRED AT THE COMMUNICATION RECEIVER INPUT =   13.00
QNR REQUIRED AT THE INTERCEPT RECEIVER INPUT =   10.00
ANTENNA POLARIZATION IS V
FREQUENCY = 300.00 MHz
TRANSMITTER ANTENNA GAIN IN THE DIRECTION OF THE COMMUNICATION LINK RECEIVER =    3.00
TRANSMITTER ANTENNA GAIN IN THE DIRECTION OF THE INTERCEPT RECEIVER ANTENNA =    1.00
INTERCEPT RECEIVER ANTENNA GAIN IN THE DIRECTION OF THE TRANSMITTER ANTENNA =    6.00
INTERCEPT RECEIVER TIME-BANDWIDTH PRODUCT = 1000.00
TRANSMISSION LINE LOSSES =    0.50 dB
CONDUCTIVITY =    0.02 mho/m
PERMITTIVITY =   25.00
INTERCEPT RECEIVER NOISE FIGURE =    6.00 dB
COMMUNICATION RECEIVER RESOLUTION BANDWIDTH = 25000.00 Hz
SPREAD SPECTRUM BANDWIDTH =  100.00 MHz
INTERCEPT RECEIVER RESOLUTION BANDWIDTH = 25000.00 Hz
INTERCEPT RECEIVER LOSS =    2.00 MHz
COMMUNICATION RECEIVER NOISE FIGURE =   10.00 dB
SURFACE REFRACTIVITY COEFFICIENT =  300.00
TERRAIN PARAMETER DELTA =  200.00


INTERCEPT RECEIVER DATA HAS BEEN CHOSEN


DUE TO THE REQUIRED SNR OF   10.00 dB AT THE RECEIVER INPUT
A RECEIVER SENSITIVITY OF  -78.00 dBm IS NEEDED


****** INTERCEPT   INTANTGAIN=6   TXINTGAIN=1   ********
```

Distance (miles)	Free Space Losses (dB)	Excess Losses (dB)	Signal-to-Receiver Sensitivity: Free Space R-Squared Propagation (dB above Receiver Sensitivity)	Ground R-Squared Propagation	Ground R-Fourth Propagation
0.50	80.10	27.86	52.40	24.53	26.42
1.00	86.13	30.63	46.37	15.75	11.61
1.50	89.65	30.88	42.85	11.97	4.31
2.00	92.15	31.14	40.35	9.21	
2.50	94.08	31.39	38.42	7.02	
3.00	95.67	31.65	36.83	5.18	
3.50	97.01	31.91	35.49	3.59	
4.00	98.17	32.16	34.33	2.17	
4.50	99.19	32.42	33.31	0.89	
5.00	100.10	32.67	32.40		

THE Following PAGES

```
TRANSMITTER ANTENNA HEIGHT =   10.00 FT
TRANSMITTER ERP =   100.00 Watts
COMMUNICATION RECEIVER LOSS =    2.00 dB
COMMUNICATION RECEIVER ANTENNA GAIN IN THE DIRECTION OF THE TRANSMITTER =    3.00
COMMUNICATION RECEIVER ANTENNA HEIGHT =   10.00 FT
INTERCEPT RECEIVER ANTENNA HEIGHT =   60.00 FT
SNR REQUIRED AT THE COMMUNICATION RECEIVER INPUT =   13.00
QNR REQUIRED AT THE INTERCEPT RECEIVER INPUT =   10.00
ANTENNA POLARIZATION IS V
FREQUENCY = 300.00 MHz
TRANSMITTER ANTENNA GAIN IN THE DIRECTION OF THE COMMUNICATION LINK RECEIVER =    3.00
TRANSMITTER ANTENNA GAIN IN THE DIRECTION OF THE INTERCEPT RECEIVER ANTENNA =    3.00
INTERCEPT RECEIVER ANTENNA GAIN IN THE DIRECTION OF THE TRANSMITTER ANTENNA =    6.00
INTERCEPT RECEIVER TIME-BANDWIDTH PRODUCT = 1000.00
TRANSMISSION LINE LOSSES =    0.50 dB
CONDUCTIVITY =    0.02 mho/m
PERMITTIVITY =   25.00
INTERCEPT RECEIVER NOISE FIGURE =    6.00 dB
COMMUNICATION RECEIVER RESOLUTION BANDWIDTH = 25000.00 Hz
SPREAD SPECTRUM BANDWIDTH =  100.00 MHz
INTERCEPT RECEIVER RESOLUTION BANDWIDTH = 25000.00 Hz
INTERCEPT RECEIVER LOSS =    2.00 MHz
COMMUNICATION RECEIVER NOISE FIGURE =   10.00 dB
SURFACE REFRACTIVITY COEFFICIENT =  300.00
TERRAIN PARAMETER DELTA =  200.00


INTERCEPT RECEIVER DATA HAS BEEN CHOSEN


DUE TO THE REQUIRED SNR OF   10.00 dB AT THE RECEIVER INPUT
A RECEIVER SENSITIVITY OF  -78.00 dBm IS NEEDED


******  INTERCEPT  INTANTGAIN=6  TXINTGAIN=3  *******
```

Distance (miles)	Free Space Losses (dB)	Excess Losses (dB)	Signal-to-Receiver Sensitivity: Free Space R-Squared Propagation (dB above Receiver Sensitivity)	Ground R-Squared Propagation	Ground R-Fourth Propagation
0.50	80.10	27.86	54.40	26.53	28.42
1.00	86.13	30.63	48.37	17.75	13.61
1.50	89.65	30.88	44.85	13.97	6.31
2.00	92.15	31.14	42.35	11.21	1.06
2.50	94.08	31.39	40.42	9.02	
3.00	95.67	31.65	38.83	7.18	
3.50	97.01	31.91	37.49	5.59	
4.00	98.17	32.16	36.33	4.17	
4.50	99.19	32.42	35.31	2.89	
5.00	100.10	32.67	34.40	1.72	
5.50	100.93	32.93	33.57	0.64	
6.00	101.69	33.18	32.81		

TRANSMITTER ANTENNA HEIGHT = 10.00 FT
TRANSMITTER ERP = 100.00 Watts
COMMUNICATION RECEIVER LOSS = 2.00 dB
COMMUNICATION RECEIVER ANTENNA GAIN IN THE DIRECTION OF THE TRANSMITTER = 3.00
COMMUNICATION RECEIVER ANTENNA HEIGHT = 10.00 FT
INTERCEPT RECEIVER ANTENNA HEIGHT = 60.00 FT
SNR REQUIRED AT THE COMMUNICATION RECEIVER INPUT = 13.00
ONR REQUIRED AT THE INTERCEPT RECEIVER INPUT = 10.00
ANTENNA POLARIZATION IS V
FREQUENCY = 300.00 MHz
TRANSMITTER ANTENNA GAIN IN THE DIRECTION OF THE COMMUNICATION LINK RECEIVER = 3.00
TRANSMITTER ANTENNA GAIN IN THE DIRECTION OF THE INTERCEPT RECEIVER ANTENNA = 6.00
INTERCEPT RECEIVER ANTENNA GAIN IN THE DIRECTION OF THE TRANSMITTER ANTENNA = 6.00
INTERCEPT RECEIVER TIME-BANDWIDTH PRODUCT = 1000.00
TRANSMISSION LINE LOSSES = 0.50 dB
CONDUCTIVITY = 0.02 mho/m
PERMITTIVITY = 25.00
INTERCEPT RECEIVER NOISE FIGURE = 6.00 dB
COMMUNICATION RECEIVER RESOLUTION BANDWIDTH = 25000.00 Hz
SPREAD SPECTRUM BANDWIDTH = 100.00 MHz
INTERCEPT RECEIVER RESOLUTION BANDWIDTH = 25000.00 Hz
INTERCEPT RECEIVER LOSS = 2.00 MHz
COMMUNICATION RECEIVER NOISE FIGURE = 10.00 dB
SURFACE REFRACTIVITY COEFFICIENT = 300.00
TERRAIN PARAMETER DELTA = 200.00

INTERCEPT RECEIVER DATA HAS BEEN CHOSEN

DUE TO THE REQUIRED SNR OF 10.00 dB AT THE RECEIVER INPUT
A RECEIVER SENSITIVITY OF -78.00 dBm IS NEEDED

****** INTERCEPT INTANTGAIN=6 TXINTGAIN=6 ********

Distance (miles)	Free Space Losses (dB)	Excess Losses (dB)	Signal-to-Receiver Sensitivity: Free Space R-Squared Propagation (dB above Receiver Sensitivity)	Ground R-Squared Propagation	Ground R-Fourth Propagation
0.50	80.10	27.86	57.40	29.53	31.42
1.00	86.13	30.63	51.37	20.75	16.61
1.50	89.65	30.88	47.85	16.97	9.31
2.00	92.15	31.14	45.35	14.21	4.06
2.50	94.08	31.39	43.42	12.02	
3.00	95.67	31.65	41.83	10.18	
3.50	97.01	31.91	40.49	8.59	
4.00	98.17	32.16	39.33	7.17	
4.50	99.19	32.42	38.31	5.89	
5.00	100.10	32.67	37.40	4.72	
5.50	100.93	32.93	36.57	3.64	
6.00	101.69	33.18	35.81	2.63	
6.50	102.38	33.44	35.12	1.68	

7.00	103.03	33.69	34.47	0.78
7.50	103.63	33.95	33.87	

TABULAR DATA FOR AIR-TO-GROUND INTERCEPT

PERFORMANCE AS A FUNCTION OF INTERCEPT RECEIVER ANTENNA GAIN

-TABULAR DATA-

(for Figure 3.2.b)

```
TRANSMITTER ANTENNA HEIGHT =    10.00 FT
TRANSMITTER ERP =    100.00 Watts
COMMUNICATION RECEIVER LOSS =     2.00 dB
COMMUNICATION RECEIVER ANTENNA GAIN IN THE DIRECTION OF THE TRANSMITTER =    3.00
COMMUNICATION RECEIVER ANTENNA HEIGHT =    10.00 FT
INTERCEPT RECEIVER ANTENNA HEIGHT =    60.00 FT
SNR REQUIRED AT THE COMMUNICATION RECEIVER INPUT =    13.00
QNR REQUIRED AT THE INTERCEPT RECEIVER INPUT =    10.00
ANTENNA POLARIZATION IS V
FREQUENCY = 300.00 MHz
TRANSMITTER ANTENNA GAIN IN THE DIRECTION OF THE COMMUNICATION LINK RECEIVER =    3.00
TRANSMITTER ANTENNA GAIN IN THE DIRECTION OF THE INTERCEPT RECEIVER ANTENNA =    1.00
INTERCEPT RECEIVER ANTENNA GAIN IN THE DIRECTION OF THE TRANSMITTER ANTENNA =    1.00
INTERCEPT RECEIVER TIME-BANDWIDTH PRODUCT = 1000.00
TRANSMISSION LINE LOSSES =     0.50 dB
CONDUCTIVITY =     0.02 mho/m
PERMITTIVITY =    25.00
INTERCEPT RECEIVER NOISE FIGURE =     6.00 dB
COMMUNICATION RECEIVER RESOLUTION BANDWIDTH = 25000.00 Hz
SPREAD SPECTRUM BANDWIDTH =   100.00 MHz
INTERCEPT RECEIVER RESOLUTION BANDWIDTH = 25000.00 Hz
INTERCEPT RECEIVER LOSS =     2.00 MHz
COMMUNICATION RECEIVER NOISE FIGURE =    10.00 dB
SURFACE REFRACTIVITY COEFFICIENT =   300.00
TERRAIN PARAMETER DELTA =   200.00


INTERCEPT RECEIVER DATA HAS BEEN CHOSEN


DUE TO THE REQUIRED SNR OF    10.00 dB AT THE RECEIVER INPUT
A RECEIVER SENSITIVITY OF  -78.00 dBm IS NEEDED


********  INTERCEPT  INTANTGAIN=1  *********
```

Distance	Free Space Losses	Excess Losses	Signal-to-Receiver Sensitivity: Free Space R-Squared Propagation	Ground R-Squared Propagation	Ground R-Fourth Propagation
(miles)	(dB)	(dB)	(dB above Receiver Sensitivity)		
0.50	80.10	27.86	47.40	19.53	21.42
1.00	86.13	30.63	41.37	10.75	6.61
1.50	89.65	30.80	37.85	6.97	
2.00	92.15	31.14	35.35	4.21	
2.50	94.08	31.39	33.42	2.02	
3.00	95.67	31.65	31.83	0.18	
3.50	97.01	31.91	30.49		

TRANSMITTER ANTENNA HEIGHT = 10.00 FT
TRANSMITTER ERP = 100.00 Watts
COMMUNICATION RECEIVER LOSS = 2.00 dB
COMMUNICATION RECEIVER ANTENNA GAIN IN THE DIRECTION OF THE TRANSMITTER = 3.00
COMMUNICATION RECEIVER ANTENNA HEIGHT = 10.00 FT
INTERCEPT RECEIVER ANTENNA HEIGHT = 60.00 FT
SNR REQUIRED AT THE COMMUNICATION RECEIVER INPUT = 13.00
QNR REQUIRED AT THE INTERCEPT RECEIVER INPUT = 10.00
ANTENNA POLARIZATION IS V
FREQUENCY = 300.00 MHz
TRANSMITTER ANTENNA GAIN IN THE DIRECTION OF THE COMMUNICATION LINK RECEIVER = 3.00
TRANSMITTER ANTENNA GAIN IN THE DIRECTION OF THE INTERCEPT RECEIVER ANTENNA = 1.00
INTERCEPT RECEIVER ANTENNA GAIN IN THE DIRECTION OF THE TRANSMITTER ANTENNA = 3.00
INTERCEPT RECEIVER TIME-BANDWIDTH PRODUCT = 1000.00
TRANSMISSION LINE LOSSES = 0.50 dB
CONDUCTIVITY = 0.02 mho/m
PERMITTIVITY = 25.00
INTERCEPT RECEIVER NOISE FIGURE = 6.00 dB
COMMUNICATION RECEIVER RESOLUTION BANDWIDTH = 25000.00 Hz
SPREAD SPECTRUM BANDWIDTH = 100.00 MHz
INTERCEPT RECEIVER RESOLUTION BANDWIDTH = 25000.00 Hz
INTERCEPT RECEIVER LOSS = 2.00 MHz
COMMUNICATION RECEIVER NOISE FIGURE = 10.00 dB
SURFACE REFRACTIVITY COEFFICIENT = 300.00
TERRAIN PARAMETER DELTA = 200.00

INTERCEPT RECEIVER DATA HAS BEEN CHOSEN

DUE TO THE REQUIRED SNR OF 10.00 dB AT THE RECEIVER INPUT
A RECEIVER SENSITIVITY OF -78.00 dBm IS NEEDED

****** INTERCEPT INTANTGAIN=3 ********

Distance (miles)	Free Space Losses (dB)	Excess Losses (dB)	Signal-to-Receiver Sensitivity (dB above Receiver Sensitivity): Free Space R-Squared Propagation	Ground R-Squared Propagation	Ground R-Fourth Propagation
0.50	80.10	27.86	49.40	21.53	23.42
1.00	86.13	30.63	43.37	12.75	8.61
1.50	89.65	30.88	39.85	8.97	1.31
2.00	92.15	31.14	37.35	6.21	
2.50	94.08	31.39	35.42	4.02	
3.00	95.67	31.65	33.83	2.18	
3.50	97.01	31.91	32.49	0.59	
4.00	98.17	32.16	31.33		

TRANSMITTER ANTENNA HEIGHT = 10.00 FT
TRANSMITTER ERP = 100.00 Watts
COMMUNICATION RECEIVER LOSS = 2.00 dB
COMMUNICATION RECEIVER ANTENNA GAIN IN THE DIRECTION OF THE TRANSMITTER = 3.00
COMMUNICATION RECEIVER ANTENNA HEIGHT = 10.00 FT
INTERCEPT RECEIVER ANTENNA HEIGHT = 60.00 FT
SNR REQUIRED AT THE COMMUNICATION RECEIVER INPUT = 13.00
QNR REQUIRED AT THE INTERCEPT RECEIVER INPUT = 10.00
ANTENNA POLARIZATION IS V
FREQUENCY = 300.00 MHz
TRANSMITTER ANTENNA GAIN IN THE DIRECTION OF THE COMMUNICATION LINK RECEIVER = 3.00
TRANSMITTER ANTENNA GAIN IN THE DIRECTION OF THE INTERCEPT RECEIVER ANTENNA = 1.00
INTERCEPT RECEIVER ANTENNA GAIN IN THE DIRECTION OF THE TRANSMITTER ANTENNA = 6.00
INTERCEPT RECEIVER TIME-BANDWIDTH PRODUCT = 1000.00
TRANSMISSION LINE LOSSES = 0.50 dB
CONDUCTIVITY = 0.02 mho/m
PERMITTIVITY = 25.00
INTERCEPT RECEIVER NOISE FIGURE = 6.00 dB
COMMUNICATION RECEIVER RESOLUTION BANDWIDTH = 25000.00 Hz
SPREAD SPECTRUM BANDWIDTH = 100.00 MHz
INTERCEPT RECEIVER RESOLUTION BANDWIDTH = 25000.00 Hz
INTERCEPT RECEIVER LOSS = 2.00 MHz
COMMUNICATION RECEIVER NOISE FIGURE = 10.00 dB
SURFACE REFRACTIVITY COEFFICIENT = 300.00
TERRAIN PARAMETER DELTA = 200.00

INTERCEPT RECEIVER DATA HAS BEEN CHOSEN

DUE TO THE REQUIRED SNR OF 10.00 dB AT THE RECEIVER INPUT
A RECEIVER SENSITIVITY OF -78.00 dBm IS NEEDED

****** INTERCEPT INTANTGAIN=6 *********

Distance	Free Space Losses	Excess Losses	Signal-to-Receiver Sensitivity: Free Space R-Squared Propagation	Ground R-Squared Propagation	Ground R-Fourth Propagation
(miles)	(dB)	(dB)	(dB above Receiver Sensitivity)		
0.50	80.10	27.86	52.40	24.53	26.42
1.00	86.13	30.63	46.37	15.75	11.61
1.50	89.65	30.88	42.85	11.97	4.31
2.00	92.15	31.14	40.35	9.21	
2.50	94.08	31.39	38.42	7.02	
3.00	95.67	31.65	36.83	5.18	
3.50	97.01	31.91	35.49	3.59	
4.00	98.17	32.16	34.33	2.17	
4.50	99.19	32.42	33.31	0.89	
5.00	100.10	32.67	32.40		

TRANSMITTER ANTENNA HEIGHT = 10.00 FT
TRANSMITTER ERP = 100.00 Watts
COMMUNICATION RECEIVER LOSS = 2.00 dB
COMMUNICATION RECEIVER ANTENNA GAIN IN THE DIRECTION OF THE TRANSMITTER = 3.00
COMMUNICATION RECEIVER ANTENNA HEIGHT = 10.00 FT
INTERCEPT RECEIVER ANTENNA HEIGHT = 60.00 FT
SNR REQUIRED AT THE COMMUNICATION RECEIVER INPUT = 13.00
QNR REQUIRED AT THE INTERCEPT RECEIVER INPUT = 10.00
ANTENNA POLARIZATION IS V
FREQUENCY = 300.00 MHz
TRANSMITTER ANTENNA GAIN IN THE DIRECTION OF THE COMMUNICATION LINK RECEIVER = 3.00
TRANSMITTER ANTENNA GAIN IN THE DIRECTION OF THE INTERCEPT RECEIVER ANTENNA = 1.00
INTERCEPT RECEIVER ANTENNA GAIN IN THE DIRECTION OF THE TRANSMITTER ANTENNA = 10.00
INTERCEPT RECEIVER TIME-BANDWIDTH PRODUCT = 1000.00
TRANSMISSION LINE LOSSES = 0.50 dB
CONDUCTIVITY = 0.02 mho/m
PERMITTIVITY = 25.00
INTERCEPT RECEIVER NOISE FIGURE = 6.00 dB
COMMUNICATION RECEIVER RESOLUTION BANDWIDTH = 25000.00 Hz
SPREAD SPECTRUM BANDWIDTH = 100.00 MHz
INTERCEPT RECEIVER RESOLUTION BANDWIDTH = 25000.00 Hz
INTERCEPT RECEIVER LOSS = 2.00 MHz
COMMUNICATION RECEIVER NOISE FIGURE = 10.00 dB
SURFACE REFRACTIVITY COEFFICIENT = 300.00
TERRAIN PARAMETER DELTA = 200.00

INTERCEPT RECEIVER DATA HAS BEEN CHOSEN

DUE TO THE REQUIRED SNR OF 10.00 dB AT THE RECEIVER INPUT
A RECEIVER SENSITIVITY OF -78.00 dBm IS NEEDED

****** INTERCEPT INTANTGAIN=10 ********

Distance (miles)	Free Space Losses (dB)	Excess Losses (dB)	Signal-to-Receiver Sensitivity: Free Space R-Squared Propagation (dB above Receiver Sensitivity)	Ground R-Squared Propagation	Ground R-Fourth Propagation
0.50	80.10	27.86	56.40	28.53	30.42
1.00	86.13	30.63	50.37	19.75	15.61
1.50	89.65	30.88	46.85	15.97	8.31
2.00	92.15	31.14	44.35	13.21	3.06
2.50	94.08	31.39	42.42	11.02	
3.00	95.67	31.65	40.83	9.18	
3.50	97.01	31.91	39.49	7.59	
4.00	98.17	32.16	38.33	6.17	
4.50	99.19	32.42	37.31	4.89	
5.00	100.10	32.67	36.40	3.72	
5.50	100.93	32.93	35.57	2.64	
6.00	101.69	33.18	34.81	1.63	
6.50	102.38	33.44	34.12	0.68	

7.ØØ	1Ø3.Ø3	33.69	33.47

TABULAR DATA FOR AIR-TO-GROUND INTERCEPT

LINK SIGNAL-TO-RECEIVER SENSITIVITY vs. ANTENNA HEIGHT

(for Figure 3.3)

```
TRANSMITTER ANTENNA HEIGHT =   10.00 FT
TRANSMITTER ERP =   100.00 Watts
COMMUNICATION RECEIVER LOSS =    2.00 dB
COMMUNICATION RECEIVER ANTENNA GAIN IN THE DIRECTION OF THE TRANSMITTER =    3.00
COMMUNICATION RECEIVER ANTENNA HEIGHT = 10 feet
INTERCEPT RECEIVER ANTENNA HEIGHT =   from 10 feet to 300 feet
SNR REQUIRED AT THE COMMUNICATION RECEIVER INPUT =   13.00
QNR REQUIRED AT THE INTERCEPT RECEIVER INPUT =   10.00
ANTENNA POLARIZATION IS V
FREQUENCY = 300.00 MHz
TRANSMITTER ANTENNA GAIN IN THE DIRECTION OF THE COMMUNICATION LINK RECEIVER =    3.00
TRANSMITTER ANTENNA GAIN IN THE DIRECTION OF THE INTERCEPT RECEIVER ANTENNA =    1.00
INTERCEPT RECEIVER ANTENNA GAIN IN THE DIRECTION OF THE TRANSMITTER ANTENNA =    6.00
INTERCEPT RECEIVER TIME-BANDWIDTH PRODUCT = 1000.00
TRANSMISSION LINE LOSSES =    0.50 dB
CONDUCTIVITY =    0.02 mho/m
PERMITTIVITY =   25.00
INTERCEPT RECEIVER NOISE FIGURE =    6.00 dB
COMMUNICATION RECEIVER RESOLUTION BANDWIDTH = 25000.00 Hz
SPREAD SPECTRUM BANDWIDTH =  100.00 MHz
INTERCEPT RECEIVER RESOLUTION BANDWIDTH = 25000.00 Hz
INTERCEPT RECEIVER LOSS =    2.00 MHz
COMMUNICATION RECEIVER NOISE FIGURE =   10.00 dB
SURFACE REFRACTIVITY COEFFICIENT =  300.00
TERRAIN PARAMETER DELTA =  200.00


INTERCEPT RECEIVER DATA HAS BEEN CHOSEN


DUE TO THE REQUIRED SNR OF   10.00 dB AT THE RECEIVER INPUT
A RECEIVER SENSITIVITY OF  -78.00 dBm IS NEEDED
```

Program Input Data for 100 watt ERP

PROGRAM OUTPUT DATA FOR 100 Watt ERP

INTERCEPT ANTENNA HEIGHT (ft)		SIGNAL-TO-RECEIVER SENSITIVITY @ 1 MILE(dB)
10		9.31
20		11.88
30		13.56
40		14.53
50		15.19
60	Losses are computed by the "ITM"	15.75
70	Diffraction Loss equation	16.16
80		16.52
90		16.85
100		17.15
110		17.42
120		17.90
130		19.65
140		21.44
150	Losses are computed by the "ITM"	23.28
160	Line-of-Sight Loss equation	25.16
170		27.07
180		29.03
190		31.03
200		33.06
210		35.14
220		37.24
230		39.39
240		41.56
250		43.77
260		46.02
270		46.37
280		46.37
290		46.37
300		46.37

TRANSMITTER ANTENNA HEIGHT = 10.00 FT
TRANSMITTER ERP = 10.00 Watts
COMMUNICATION RECEIVER LOSS = 2.00 dB
COMMUNICATION RECEIVER ANTENNA GAIN IN THE DIRECTION OF THE TRANSMITTER = 3.00
COMMUNICATION RECEIVER ANTENNA HEIGHT = 10.00 FT
INTERCEPT RECEIVER ANTENNA HEIGHT = from 20.00 FT To 300.00 FT
SNR REQUIRED AT THE COMMUNICATION RECEIVER INPUT = 13.00
QNR REQUIRED AT THE INTERCEPT RECEIVER INPUT = 10.00
ANTENNA POLARIZATION IS V
FREQUENCY = 300.00 MHz
TRANSMITTER ANTENNA GAIN IN THE DIRECTION OF THE COMMUNICATION LINK RECEIVER = 3.00
TRANSMITTER ANTENNA GAIN IN THE DIRECTION OF THE INTERCEPT RECEIVER ANTENNA = 1.00
INTERCEPT RECEIVER ANTENNA GAIN IN THE DIRECTION OF THE TRANSMITTER ANTENNA = 6.00
INTERCEPT RECEIVER TIME-BANDWIDTH PRODUCT = 1000.00
TRANSMISSION LINE LOSSES = 0.50 dB
CONDUCTIVITY = 0.02 mho/m
PERMITTIVITY = 25.00
INTERCEPT RECEIVER NOISE FIGURE = 6.00 dB
COMMUNICATION RECEIVER RESOLUTION BANDWIDTH = 25000.00 Hz
SPREAD SPECTRUM BANDWIDTH = 100.00 MHz
INTERCEPT RECEIVER RESOLUTION BANDWIDTH = 25000.00 Hz
INTERCEPT RECEIVER LOSS = 2.00 MHz
COMMUNICATION RECEIVER NOISE FIGURE = 10.00 dB
SURFACE REFRACTIVITY COEFFICIENT = 300.00
TERRAIN PARAMETER DELTA = 200.00

INTERCEPT RECEIVER DATA HAS BEEN CHOSEN

DUE TO THE REQUIRED SNR OF 10.00 dB AT THE RECEIVER INPUT
A RECEIVER SENSITIVITY OF -78.00 dBm IS NEEDED

Program Input Data for 10 watt ERP

PROGRAM OUTPUT DATA FOR 10 WATT ERP

INTERCEPT ANTENNA HEIGHT (ft)		SIGNAL-TO-RECEIVER SENSITIVITY @ 1 MILE(dB)
10		0
20		1.88
30	Losses are computed by the "ITM"	3.56
40	Diffraction Loss equation	4.53
50		5.19
60		5.75
70		6.16
80		6.52
90		6.85
100		7.15
110		7.42
120		7.90
130		9.65
140		11.44
150		13.28
160	Losses are computed by the "ITM"	15.16
170	Line-of-Sight Loss equation	17.07
180		19.03
190		21.03
200		23.06
210		25.14
220		27.24
230		29.39
240		31.56
250		33.77
260		36.02
270		36.37
280		36.37
290		36.37
300		36.37

TABULAR DATA FOR GROUND-TO-GROUND COMMUNICATION LINK
PERFORMANCE AS A FUNCTION OF ANTENNA
POLARIZATION FOR AN OPERATIONAL FREQUENCY
OF 50 MHz
(for Figure 3.4.a)

```
TRANSMITTER ANTENNA HEIGHT =   10.00 FT
TRANSMITTER ERP =   100.00 Watts
COMMUNICATION RECEIVER LOSS =    2.00 dB
COMMUNICATION RECEIVER ANTENNA GAIN IN THE DIRECTION OF THE TRANSMITTER =    3.00
COMMUNICATION RECEIVER ANTENNA HEIGHT =   10.00 FT
INTERCEPT RECEIVER ANTENNA HEIGHT =   60.00 FT
SNR REQUIRED AT THE COMMUNICATION RECEIVER INPUT =   13.00
QNR REQUIRED AT THE INTERCEPT RECEIVER INPUT =   10.00
ANTENNA POLARIZATION IS V
FREQUENCY =  50.00 MHz
TRANSMITTER ANTENNA GAIN IN THE DIRECTION OF THE COMMUNICATION LINK RECEIVER =    3.00
TRANSMITTER ANTENNA GAIN IN THE DIRECTION OF THE INTERCEPT RECEIVER ANTENNA =    1.00
INTERCEPT RECEIVER ANTENNA GAIN IN THE DIRECTION OF THE TRANSMITTER ANTENNA =    6.00
INTERCEPT RECEIVER TIME-BANDWIDTH PRODUCT = 1000.00
TRANSMISSION LINE LOSSES =    0.50 dB
CONDUCTIVITY =    0.02 mho/m
PERMITTIVITY =   25.00
INTERCEPT RECEIVER NOISE FIGURE =    6.00 dB
COMMUNICATION RECEIVER RESOLUTION BANDWIDTH = 25000.00 Hz
SPREAD SPECTRUM BANDWIDTH =   100.00 MHz
INTERCEPT RECEIVER RESOLUTION BANDWIDTH = 25000.00 Hz
INTERCEPT RECEIVER LOSS =    2.00 MHz
COMMUNICATION RECEIVER NOISE FIGURE =   10.00 dB
SURFACE REFRACTIVITY COEFFICIENT =  300.00
TERRAIN PARAMETER DELTA =  200.00


COMMUNICATIONS RECEIVER DATA HAS BEEN CHOSEN


DUE TO THE REQUIRED SNR OF   13.00 dB AT THE RECEIVER INPUT
A RECEIVER SENSITIVITY OF -107.02 dBm IS NEEDED


******  COMMS WITH VERTICAL ANTENNA POLARIZATION  ******
```

Distance (miles)	Free Space Losses (dB)	Excess Losses (dB)	Signal-to-Receiver Sensitivity: Free Space R-Squared Propagation (dB above Receiver Sensitivity)	Signal-to-Receiver Sensitivity: Ground R-Squared Propagation (dB above Receiver Sensitivity)	Signal-to-Receiver Sensitivity: Ground R-Fourth Propagation (dB above Receiver Sensitivity)
0.50	64.54	39.46	95.98	56.52	58.41
1.00	70.56	39.66	89.96	50.30	46.17
1.50	74.08	39.85	86.44	46.59	38.93
2.00	76.58	40.04	83.94	43.89	33.74
2.50	78.52	40.24	82.00	41.76	29.67
3.00	80.10	40.43	80.42	39.98	26.31
3.50	81.44	40.63	79.08	38.45	23.44
4.00	82.60	40.82	77.92	37.10	20.92
4.50	83.63	41.01	76.89	35.88	18.68
5.00	84.54	41.21	75.98	34.77	16.66
5.50	85.37	41.40	75.15	33.75	14.81
6.00	86.13	41.60	74.40	32.80	13.10
6.50	86.82	41.79	73.70	31.91	11.52

7.00	87.46	41.99	73.06	31.07	10.04
7.50	88.06	42.18	72.46	30.28	8.64
8.00	88.62	42.37	71.90	29.52	7.33
8.50	89.15	42.57	71.37	28.80	6.08
9.00	89.65	42.76	70.87	28.11	4.89
9.50	90.12	42.96	70.40	27.45	3.76
10.00	90.56	43.15	69.96	26.81	2.67
10.50	90.99	43.35	69.53	26.19	1.63
11.00	91.39	43.54	69.13	25.59	0.63
11.50	91.78	43.73	68.74	25.01	
12.00	92.15	43.93	68.37	24.45	
12.50	92.50	44.12	68.02	23.90	
13.00	92.84	44.32	67.68	23.36	
13.50	93.17	44.51	67.35	22.84	
14.00	93.48	44.71	67.04	22.33	
14.50	93.79	44.90	66.73	21.83	
15.00	94.08	45.09	66.44	21.34	
15.50	94.37	45.29	66.15	20.86	
16.00	94.64	45.48	65.88	20.39	
16.50	94.91	45.68	65.61	19.93	
17.00	95.17	45.87	65.35	19.48	
17.50	95.42	46.07	65.10	19.03	
18.00	95.67	46.26	64.85	18.59	
18.50	95.91	46.45	64.61	18.16	
19.00	96.14	46.65	64.38	17.73	
19.50	96.36	46.84	64.16	17.31	
20.00	96.58	47.04	63.94	16.90	
20.50	96.80	47.23	63.72	16.49	
21.00	97.01	47.43	63.51	16.09	
21.50	97.21	47.62	63.31	15.69	
22.00	97.41	47.81	63.11	15.30	
22.50	97.61	48.01	62.91	14.91	
23.00	97.80	48.20	62.72	14.52	
23.50	97.98	48.40	62.54	14.14	
24.00	98.17	48.59	62.35	13.76	
24.50	98.35	48.79	62.17	13.39	
25.00	98.52	48.98	62.00	13.02	
25.50	98.69	49.17	61.83	12.65	
26.00	98.86	49.37	61.66	12.29	
26.50	99.03	49.56	61.49	11.93	
27.00	99.19	49.76	61.33	11.57	
27.50	99.35	49.95	61.17	11.22	
28.00	99.51	50.14	61.02	10.87	
28.50	99.66	50.34	60.86	10.52	
29.00	99.81	50.53	60.71	10.18	
29.50	99.96	50.73	60.56	9.83	
30.00	100.10	50.92	60.42	9.49	
30.50	100.25	51.12	60.27	9.16	
31.00	100.39	51.31	60.13	8.82	
31.50	100.53	51.50	59.99	8.49	
32.00	100.67	51.70	59.86	8.16	
32.50	100.80	51.89	59.72	7.83	
33.00	100.93	52.09	59.59	7.50	
33.50	101.06	52.28	59.46	7.18	
34.00	101.19	52.48	59.33	6.85	
34.50	101.32	52.67	59.20	6.53	
35.00	101.44	52.86	59.08	6.21	
35.50	101.57	53.06	58.95	5.89	
36.00	101.69	53.25	58.83	5.58	
36.50	101.81	53.45	58.71	5.27	
37.00	101.93	53.64	58.59	4.95	

37.50	102.04	53.84	58.48	4.64
38.00	102.16	54.03	58.36	4.33
38.50	102.27	54.22	58.25	4.02
39.00	102.38	54.42	58.14	3.72
39.50	102.49	54.61	58.03	3.41
40.00	102.60	54.81	57.92	3.11
40.50	102.71	55.00	57.81	2.81
41.00	102.82	55.20	57.70	2.51
41.50	102.92	55.39	57.60	2.21
42.00	103.03	55.58	57.49	1.91
42.50	103.13	55.78	57.39	1.61
43.00	103.23	55.97	57.29	1.32
43.50	103.33	56.17	57.19	1.02
44.00	103.43	56.36	57.09	0.73
44.50	103.53	56.56	56.99	0.44
45.00	103.63	56.75	56.89	0.14
45.50	103.72	56.94	56.80	

TRANSMITTER ANTENNA HEIGHT = 10.00 FT
TRANSMITTER ERP = 100.00 Watts
COMMUNICATION RECEIVER LOSS = 2.00 dB
COMMUNICATION RECEIVER ANTENNA GAIN IN THE DIRECTION OF THE TRANSMITTER = 3.00
COMMUNICATION RECEIVER ANTENNA HEIGHT = 10.00 FT
INTERCEPT RECEIVER ANTENNA HEIGHT = 60.00 FT
SNR REQUIRED AT THE COMMUNICATION RECEIVER INPUT = 13.00
QNR REQUIRED AT THE INTERCEPT RECEIVER INPUT = 10.00
ANTENNA POLARIZATION IS H
FREQUENCY = 50.00 MHz
TRANSMITTER ANTENNA GAIN IN THE DIRECTION OF THE COMMUNICATION LINK RECEIVER = 3.00
TRANSMITTER ANTENNA GAIN IN THE DIRECTION OF THE INTERCEPT RECEIVER ANTENNA = 1.00
INTERCEPT RECEIVER ANTENNA GAIN IN THE DIRECTION OF THE TRANSMITTER ANTENNA = 6.00
INTERCEPT RECEIVER TIME-BANDWIDTH PRODUCT = 1000.00
TRANSMISSION LINE LOSSES = 0.50 dB
CONDUCTIVITY = 0.02 mho/m
PERMITTIVITY = 25.00
INTERCEPT RECEIVER NOISE FIGURE = 6.00 dB
COMMUNICATION RECEIVER RESOLUTION BANDWIDTH = 25000.00 Hz
SPREAD SPECTRUM BANDWIDTH = 100.00 MHz
INTERCEPT RECEIVER RESOLUTION BANDWIDTH = 25000.00 Hz
INTERCEPT RECEIVER LOSS = 2.00 MHz
COMMUNICATION RECEIVER NOISE FIGURE = 10.00 dB
SURFACE REFRACTIVITY COEFFICIENT = 300.00
TERRAIN PARAMETER DELTA = 200.00

COMMUNICATIONS RECEIVER DATA HAS BEEN CHOSEN

DUE TO THE REQUIRED SNR OF 13.00 dB AT THE RECEIVER INPUT
A RECEIVER SENSITIVITY OF -107.02 dBm IS NEEDED

***** COMMS WITH HORIZONTAL ANTENNA POLARIZATION ******

Distance	Free Space Losses	Excess Losses	Signal-to-Receiver Sensitivity: Free Space R-Squared Propagation	Ground R-Squared Propagation	Ground R-Fourth Propagation
(miles)	(dB)	(dB)	(dB above Receiver Sensitivity)		
0.50	64.54	46.15	95.98	49.83	51.71
1.00	70.56	46.36	89.96	43.60	39.47
1.50	74.08	46.56	86.44	39.88	32.23
2.00	76.58	46.76	83.94	37.18	27.03
2.50	78.52	46.96	82.00	35.04	22.95
3.00	80.10	47.16	80.42	33.25	19.58
3.50	81.44	47.36	79.08	31.71	16.70
4.00	82.60	47.56	77.92	30.35	14.18
4.50	83.63	47.77	76.89	29.13	11.93
5.00	84.54	47.97	75.98	28.01	9.90
5.50	85.37	48.17	75.15	26.98	8.04
6.00	86.13	48.37	74.40	26.03	6.33
6.50	86.82	48.57	73.70	25.13	4.74

7.00	87.46	48.77	73.06	24.28	3.25
7.50	88.06	48.97	72.46	23.48	1.85
8.00	88.62	49.18	71.90	22.7[illegible]	0.53
8.50	89.15	49.38	71.37	21.9[illegible]	
9.00	89.65	49.58	70.87	21.[illegible]	
9.50	90.12	49.78	70.40	20.6[illegible]	
10.00	90.56	49.98	69.96	19.98	
10.50	90.99	50.18	69.53	19.35	
11.00	91.39	50.38	69.13	18.75	
11.50	91.78	50.59	68.74	18.16	
12.00	92.15	50.79	68.37	17.59	
12.50	92.50	50.99	68.02	17.03	
13.00	92.84	51.19	67.68	16.49	
13.50	93.17	51.39	67.35	15.96	
14.00	93.48	51.59	67.04	15.44	
14.50	93.79	51.79	66.73	14.94	
15.00	94.08	52.00	66.44	14.44	
15.50	94.37	52.20	66.15	13.95	
16.00	94.64	52.40	65.88	13.48	
16.50	94.91	52.60	65.61	13.01	
17.00	95.17	52.80	65.35	12.55	
17.50	95.42	53.00	65.10	12.09	
18.00	95.67	53.21	64.85	11.65	
18.50	95.91	53.41	64.61	11.21	
19.00	96.14	53.61	64.38	10.77	
19.50	96.36	53.81	64.16	10.35	
20.00	96.58	54.01	6[illegible].94	9.93	
20.50	96.80	54.21	63.72	9.51	
21.00	97.01	54.41	6[illegible].51	9.10	
21.50	97.21	54.6[illegible]	6[illegible].31	8.69	
22.00	97.41	54.8[illegible]	63.11	8.29	
22.50	97.61	55.0[illegible]	62.91	7.90	
23.00	97.80	55.2[illegible]	62.72	7.50	
23.50	97.98	55.4[illegible]	62.54	7.1[illegible]	
24.00	98.17	55.6[illegible]	62.35	6.7[illegible]	
24.50	98.35	55.82	62.17	6.35	
25.00	98.52	56.03	62.00	5.97	
25.50	98.69	56.23	61.83	5.60	
26.00	98.86	56.43	61.66	5.23	
26.50	99.03	56.63	61.49	4.86	
27.00	99.19	56.83	61.33	4.50	
27.50	99.35	57.03	61.17	4.14	
28.00	99.51	57.23	61.02	3.78	
28.50	99.66	57.44	60.86	3.43	
29.00	99.81	57.64	60.71	3.07	
29.50	99.96	57.84	60.56	2.7[illegible]	
30.00	100.10	58.04	60.42	2.38	
30.50	100.25	58.24	60.27	2.03	
31.00	100.39	58.44	60.13	1.69	
31.50	100.53	58.65	59.99	1.35	
32.00	100.67	58.85	59.86	1.01	
32.50	100.80	59.05	59.72	0.67	
33.00	100.93	59.25	59.59	0.34	
33.50	101.06	59.45	[illegible].46	0.[illegible]	
34.00	101.19	59.65	59.33		

TABULAR DATA FOR GROUND-TO-GROUND
COMMUNICATION LINK PERFORMANCE AS A FUNCTION
OF ANTENNA POLARIZATION FOR AN OPERATION FREQUENCY OF
300 MHz
(for Figure 3.4.b)

```
TRANSMITTER ANTENNA HEIGHT =    10.00 FT
TRANSMITTER ERP =    100.00 Watts
COMMUNICATION RECEIVER LOSS =     2.00 dB
COMMUNICATION RECEIVER ANTENNA GAIN IN THE DIRECTION OF THE TRANSMITTER =     3.00
COMMUNICATION RECEIVER ANTENNA HEIGHT =    10.00 FT
INTERCEPT RECEIVER ANTENNA HEIGHT =    60.00 FT
SNR REQUIRED AT THE COMMUNICATION RECEIVER INPUT =    13.00
QNR REQUIRED AT THE INTERCEPT RECEIVER INPUT =    10.00
ANTENNA POLARIZATION IS V
FREQUENCY = 300.00 MHz
TRANSMITTER ANTENNA GAIN IN THE DIRECTION OF THE COMMUNICATION LINK RECEIVER =     3.00
TRANSMITTER ANTENNA GAIN IN THE DIRECTION OF THE INTERCEPT RECEIVER ANTENNA =     1.00
INTERCEPT RECEIVER ANTENNA GAIN IN THE DIRECTION OF THE TRANSMITTER ANTENNA =     6.00
INTERCEPT RECEIVER TIME-BANDWIDTH PRODUCT = 1000.00
TRANSMISSION LINE LOSSES =     0.50 dB
CONDUCTIVITY =     0.02 mho/m
PERMITTIVITY =    25.00
INTERCEPT RECEIVER NOISE FIGURE =     6.00 dB
COMMUNICATION RECEIVER RESOLUTION BANDWIDTH = 25000.00 Hz
SPREAD SPECTRUM BANDWIDTH =   100.00 MHz
INTERCEPT RECEIVER RESOLUTION BANDWIDTH = 25000.00 Hz
INTERCEPT RECEIVER LOSS =     2.00 MHz
COMMUNICATION RECEIVER NOISE FIGURE =    10.00 dB
SURFACE REFRACTIVITY COEFFICIENT =   300.00
TERRAIN PARAMETER DELTA =   200.00
```

COMMUNICATIONS RECEIVER DATA HAS BEEN CHOSEN

DUE TO THE REQUIRED SNR OF   13.00 dB AT THE RECEIVER INPUT
A RECEIVER SENSITIVITY OF -107.02 dBm IS NEEDED

****** COMMS WITH VERTICAL ANTENNA POLARIZATION ******

Distance (miles)	Free Space Losses (dB)	Excess Losses (dB)	Signal-to-Receiver Sensitivity: Free Space R-Squared Propagation (dB above Receiver Sensitivity)	Ground R-Squared Propagation	Ground R-Fourth Propagation
0.50	80.10	36.81	89.42	43.61	45.50
1.00	86.13	37.07	74.40	37.33	33.19
1.50	89.65	37.33	70.87	33.54	25.89
2.00	92.15	37.59	68.37	30.78	20.63
2.50	94.08	37.85	66.44	28.58	16.49
3.00	95.67	38.12	64.85	26.74	13.06
3.50	97.01	38.38	63.51	25.13	10.12
4.00	98.17	38.64	62.35	23.71	7.54
4.50	99.19	38.90	61.33	22.43	5.23
5.00	100.10	39.17	60.42	21.25	3.14
5.50	100.93	39.43	59.59	20.16	1.22
6.00	101.69	39.69	58.83	19.14	
6.50	102.38	39.95	58.14	18.19	

7.00	103.03	40.21	57.49	17.28
7.50	103.63	40.48	56.89	16.42
8.00	104.19	40.74	56.33	15.60
8.50	104.71	41.00	55.81	14.81
9.00	105.21	41.26	55.31	14.05
9.50	105.68	41.52	54.84	13.32
10.00	106.13	41.79	54.40	12.61
10.50	106.55	42.05	53.97	11.92
11.00	106.95	42.31	53.57	11.26
11.50	107.34	42.57	53.18	10.61
12.00	107.71	42.83	52.81	9.98
12.50	108.06	43.10	52.46	9.36
13.00	108.40	43.36	52.12	8.76
13.50	108.73	43.62	51.79	8.17
14.00	109.05	43.88	51.47	7.59
14.50	109.35	44.15	51.17	7.02
15.00	109.65	44.41	50.87	6.47
15.50	109.93	44.67	50.59	5.92
16.00	110.21	44.93	50.31	5.38
16.50	110.48	45.19	50.05	4.85
17.00	110.73	45.46	49.79	4.33
17.50	110.99	45.72	49.53	3.82
18.00	111.23	45.98	49.29	3.31
18.50	111.47	46.24	49.05	2.81
19.00	111.70	46.50	48.82	2.32
19.50	111.93	46.77	48.59	1.83
20.00	112.15	47.03	48.37	1.35
20.50	112.36	47.29	48.16	0.87
21.00	112.57	47.55	47.95	0.40
21.50	112.77	47.81	47.75	

TRANSMITTER ANTENNA HEIGHT = 1Ø.ØØ FT
TRANSMITTER ERP = 1ØØ.ØØ Watts
COMMUNICATION RECEIVER LOSS = 2.ØØ dB
COMMUNICATION RECEIVER ANTENNA GAIN IN THE DIRECTION OF THE TRANSMITTER = 3.ØØ
COMMUNICATION RECEIVER ANTENNA HEIGHT = 1Ø.ØØ FT
INTERCEPT RECEIVER ANTENNA HEIGHT = 6Ø.ØØ FT
SNR REQUIRED AT THE COMMUNICATION RECEIVER INPUT = 13.ØØ
QNR REQUIRED AT THE INTERCEPT RECEIVER INPUT = 1Ø.ØØ
ANTENNA POLARIZATION IS H
FREQUENCY = 3ØØ.ØØ MHz
TRANSMITTER ANTENNA GAIN IN THE DIRECTION OF THE COMMUNICATION LINK RECEIVER = 3.ØØ
TRANSMITTER ANTENNA GAIN IN THE DIRECTION OF THE INTERCEPT RECEIVER ANTENNA = 1.ØØ
INTERCEPT RECEIVER ANTENNA GAIN IN THE DIRECTION OF THE TRANSMITTER ANTENNA = 6.ØØ
INTERCEPT RECEIVER TIME-BANDWIDTH PRODUCT = 1ØØØ.ØØ
TRANSMISSION LINE LOSSES = Ø.5Ø dB
CONDUCTIVITY = Ø.Ø2 mho/m
PERMITTIVITY = 25.ØØ
INTERCEPT RECEIVER NOISE FIGURE = 6.ØØ dB
COMMUNICATION RECEIVER RESOLUTION BANDWIDTH = 25ØØØ.ØØ Hz
SPREAD SPECTRUM BANDWIDTH = 1ØØ.ØØ MHz
INTERCEPT RECEIVER RESOLUTION BANDWIDTH = 25ØØØ.ØØ Hz
INTERCEPT RECEIVER LOSS = 2.ØØ MHz
COMMUNICATION RECEIVER NOISE FIGURE = 1Ø.ØØ dB
SURFACE REFRACTIVITY COEFFICIENT = 3ØØ.ØØ
TERRAIN PARAMETER DELTA = 2ØØ.ØØ

COMMUNICATIONS RECEIVER DATA HAS BEEN CHOSEN

DUE TO THE REQUIRED SNR OF 13.ØØ dB AT THE RECEIVER INPUT
A RECEIVER SENSITIVITY OF -1Ø7.Ø2 dBm IS NEEDED

***** COMMS WITH HORIZONTAL ANTENNA POLARIZATION *****

Distance (miles)	Free Space Losses (dB)	Excess Losses (dB)	Signal-to-Receiver Sensitivity: Free Space R-Squared Propagation (dB above Receiver Sensitivity)	Ground R-Squared Propagation	Ground R-Fourth Propagation
Ø.5Ø	8Ø.1Ø	36.91	8Ø.42	43.51	45.39
1.ØØ	86.13	37.17	74.4Ø	37.22	33.Ø9
1.5Ø	89.65	37.44	7Ø.87	33.44	25.78
2.ØØ	92.15	37.7Ø	68.37	3Ø.67	2Ø.52
2.5Ø	94.Ø8	37.97	66.44	28.47	16.38
3.ØØ	95.67	38.23	64.85	26.62	12.95
3.5Ø	97.Ø1	38.49	63.51	25.Ø2	1Ø.Ø1
4.ØØ	98.17	38.76	62.35	23.6Ø	7.42
4.5Ø	99.19	39.Ø2	61.33	22.31	5.11
5.ØØ	1ØØ.1Ø	39.28	6Ø.42	21.13	3.Ø2
5.5Ø	1ØØ.93	39.55	59.59	2Ø.Ø4	1.1Ø
6.ØØ	1Ø1.69	39.81	58.83	19.Ø2	
6.5Ø	1Ø2.38	4Ø.Ø8	58.14	18.Ø6	

7.00	103.03	40.34	57.49	17.15
7.50	103.63	40.60	56.89	16.29
8.00	104.19	40.87	56.33	15.47
8.50	104.71	41.13	55.81	14.68
9.00	105.21	41.39	55.31	13.92
9.50	105.68	41.66	54.84	13.18
10.00	106.13	41.92	54.40	12.47
10.50	106.55	42.19	53.97	11.79
11.00	106.95	42.45	53.57	11.12
11.50	107.34	42.71	53.18	10.47
12.00	107.71	42.98	52.81	9.84
12.50	108.06	43.24	52.46	9.22
13.00	108.40	43.50	52.12	8.61
13.50	108.73	43.77	51.79	8.02
14.00	109.05	44.03	51.47	7.44
14.50	109.35	44.30	51.17	6.87
15.00	109.65	44.56	50.87	6.31
15.50	109.93	44.82	50.59	5.77
16.00	110.21	45.09	50.31	5.23
16.50	110.48	45.35	50.05	4.70
17.00	110.73	45.61	49.79	4.17
17.50	110.99	45.88	49.53	3.66
18.00	111.23	46.14	49.29	3.15
18.50	111.47	46.41	49.05	2.65
19.00	111.70	46.67	48.82	2.15
19.50	111.93	46.93	48.59	1.66
20.00	112.15	47.20	48.37	1.18
20.50	112.36	47.46	48.16	0.70
21.00	112.57	47.72	47.95	0.23
21.50	112.77	47.99	47.75	

TABULAR DATA FOR GROUND-TO-GROUND COMMUNICATION
LINK PERFORMANCE AS A FUNCTION OF THE CENTER FREQUENCY OF OPERATION
(for Figure 3.5.a)

TRANSMITTER ANTENNA HEIGHT = 10.00 FT
TRANSMITTER ERP = 100.00 Watts
COMMUNICATION RECEIVER LOSS = 2.00 dB
COMMUNICATION RECEIVER ANTENNA GAIN IN THE DIRECTION OF THE TRANSMITTER = 3.00
COMMUNICATION RECEIVER ANTENNA HEIGHT = 10.00 FT
INTERCEPT RECEIVER ANTENNA HEIGHT = 60.00 FT
SNR REQUIRED AT THE COMMUNICATION RECEIVER INPUT = 13.00
QNR REQUIRED AT THE INTERCEPT RECEIVER INPUT = 10.00
ANTENNA POLARIZATION IS V
FREQUENCY = 20.00 MHz
TRANSMITTER ANTENNA GAIN IN THE DIRECTION OF THE COMMUNICATION LINK RECEIVER = 3.00
TRANSMITTER ANTENNA GAIN IN THE DIRECTION OF THE INTERCEPT RECEIVER ANTENNA = 1.00
INTERCEPT RECEIVER ANTENNA GAIN IN THE DIRECTION OF THE TRANSMITTER ANTENNA = 6.00
INTERCEPT RECEIVER TIME-BANDWIDTH PRODUCT = 1000.00
TRANSMISSION LINE LOSSES = 0.50 dB
CONDUCTIVITY = 0.02 mho/m
PERMITTIVITY = 25.00
INTERCEPT RECEIVER NOISE FIGURE = 6.00 dB
COMMUNICATION RECEIVER RESOLUTION BANDWIDTH = 25000.00 Hz
SPREAD SPECTRUM BANDWIDTH = 100.00 MHz
INTERCEPT RECEIVER RESOLUTION BANDWIDTH = 25000.00 Hz
INTERCEPT RECEIVER LOSS = 2.00 MHz
COMMUNICATION RECEIVER NOISE FIGURE = 10.00 dB
SURFACE REFRACTIVITY COEFFICIENT = 300.00
TERRAIN PARAMETER DELTA = 200.00

COMMUNICATIONS RECEIVER DATA HAS BEEN CHOSEN

DUE TO THE REQUIRED SNR OF 13.00 dB AT THE RECEIVER INPUT
A RECEIVER SENSITIVITY OF -107.02 dBm IS NEEDED

******* COMMUNICATIONS FREQ=20 MHz *********

Distance	Free Space Losses	Excess Losses	Signal-to-Receiver Sensitivity: Free Space R-Squared Propagation	Ground R-Squared Propagation	Ground R-Fourth Propagation
(miles)	(dB)	(dB)	(dB above Receiver Sensitivity)		
0.50	56.58	38.63	103.94	65.31	67.19
1.00	62.60	38.79	97.92	59.13	55.00
1.50	66.13	38.94	94.40	55.46	47.80
2.00	68.62	39.09	91.90	52.80	42.65
2.50	70.56	39.25	89.96	50.71	38.62
3.00	72.15	39.40	88.37	48.97	35.30
3.50	73.48	39.56	87.04	47.48	32.46
4.00	74.64	39.71	85.88	46.16	29.99
4.50	75.67	39.87	84.85	44.99	27.79
5.00	76.58	40.02	83.94	43.92	25.80
5.50	77.41	40.17	83.11	42.93	23.99
6.00	78.17	40.33	82.35	42.02	22.33
6.50	78.86	40.48	81.66	41.17	20.78

7.00	79.51	40.64	81.02	40.38	19.34
7.50	80.10	40.79	80.42	39.62	17.99
8.00	80.67	40.95	79.86	38.91	16.71
8.50	81.19	41.10	79.33	38.25	15.51
9.00	81.69	41.26	78.83	37.58	14.36
9.50	82.16	41.41	78.36	36.95	13.26
10.00	82.60	41.56	77.92	36.35	12.22
10.50	83.03	41.72	77.49	35.77	11.22
11.00	83.43	41.87	77.09	35.22	10.25
11.50	83.82	42.03	76.70	34.68	9.33
12.00	84.19	42.18	76.33	34.15	8.43
12.50	84.54	42.34	75.98	33.64	7.57
13.00	84.88	42.49	75.64	33.15	6.74
13.50	85.21	42.65	75.31	32.66	5.93
14.00	85.53	42.80	74.99	32.19	5.14
14.50	85.83	42.95	74.69	31.74	4.38
15.00	86.13	43.11	74.40	31.29	3.63
15.50	86.41	43.26	74.11	30.85	2.91
16.00	86.69	43.42	73.83	30.42	2.20
16.50	86.95	43.57	73.57	30.00	1.51
17.00	87.21	43.73	73.31	29.58	0.84
17.50	87.46	43.88	73.06	29.18	0.18
18.00	87.71	44.04	72.81	28.78	
18.50	87.95	44.19	72.57	28.38	
19.00	88.18	44.31	72.34	28.00	
19.50	88.40	44.50	72.12	27.62	
20.00	88.62	44.65	71.90	27.24	
20.50	88.84	44.81	71.68	26.87	
21.00	89.05	44.96	71.47	26.51	
21.50	89.25	45.12	71.27	26.15	
22.00	89.45	45.27	71.07	25.80	
22.50	89.65	45.42	70.87	25.45	
23.00	89.84	45.58	70.68	25.10	
23.50	90.02	45.73	70.50	24.76	
24.00	90.21	45.89	70.31	24.42	
24.50	90.39	46.04	70.13	24.09	
25.00	90.56	46.20	69.96	23.76	
25.50	90.73	46.35	69.79	23.44	
26.00	90.90	46.51	69.62	23.11	
26.50	91.07	46.66	69.45	22.79	
27.00	91.23	46.81	69.29	22.48	
27.50	91.39	46.97	69.13	22.16	
28.00	91.55	47.12	68.97	21.85	
28.50	91.70	47.28	68.82	21.54	
29.00	91.85	47.43	68.67	21.24	
29.50	92.00	47.59	68.52	20.93	
30.00	92.15	47.74	68.37	20.63	
30.50	92.29	47.90	68.23	20.34	
31.00	92.43	48.05	68.09	20.04	
31.50	92.57	48.20	67.95	19.75	
32.00	92.71	48.36	67.81	19.46	
32.50	92.84	48.51	67.68	19.17	
33.00	92.97	48.67	67.55	18.88	
33.50	93.10	48.82	67.42	18.59	
34.00	93.23	48.98	67.29	18.31	
34.50	93.36	49.13	67.16	18.03	
35.00	93.48	49.28	67.04	17.75	
35.50	93.61	49.44	66.91	17.47	
36.00	93.73	49.59	66.79	17.20	
36.50	93.85	49.75	66.67	16.92	
37.00	93.97	49.90	66.55	16.65	

37.50	94.08	50.06	66.44	16.38
38.00	94.20	50.21	66.32	16.11
38.50	94.31	50.37	66.21	15.84
39.00	94.42	50.52	66.10	15.58
39.50	94.54	50.67	65.99	15.31
40.00	94.64	50.83	65.88	15.05
40.50	94.75	50.98	65.77	14.78
41.00	94.86	51.14	65.66	14.52
41.50	94.96	51.29	65.56	14.26
42.00	95.07	51.45	65.45	14.01
42.50	95.17	51.60	65.35	13.75
43.00	95.27	51.76	65.25	13.49
43.50	95.37	51.91	65.15	13.24
44.00	95.47	52.06	65.05	12.98
44.50	95.57	52.22	64.95	12.73
45.00	95.67	52.37	64.85	12.48
45.50	95.76	52.53	64.76	12.23
46.00	95.86	52.68	64.66	11.98
46.50	95.95	52.84	64.57	11.73
47.00	96.05	52.99	64.48	11.48
47.50	96.14	53.14	64.38	11.24
48.00	96.23	53.30	64.29	10.99
48.50	96.32	53.45	64.20	10.75
49.00	96.41	53.61	64.11	10.50
49.50	96.50	53.76	64.02	10.26
50.00	96.58	53.92	63.94	10.02
50.50	96.67	54.07	63.85	9.78
51.00	96.75	54.23	63.77	9.54
51.50	96.84	54.38	63.68	9.30
52.00	96.92	54.55	63.60	9.06
52.50	97.01	54.69	63.51	8.82
53.00	97.09	54.84	63.43	8.59
53.50	97.17	55.00	63.35	8.35
54.00	97.25	55.15	63.27	8.12
54.50	97.33	55.31	63.19	7.88
55.00	97.41	55.46	63.11	7.65
55.50	97.49	55.62	63.03	7.42
56.00	97.57	55.77	62.95	7.18
56.50	97.64	55.92	62.88	6.95
57.00	97.72	56.08	62.80	6.72
57.50	97.80	56.23	62.72	6.49
58.00	97.87	56.39	62.65	6.26
58.50	97.95	56.54	62.57	6.03
59.00	98.02	56.70	62.50	5.80
59.50	98.09	56.85	62.43	5.58
60.00	98.17	57.00	62.35	5.35
60.50	98.24	57.16	62.28	5.12
61.00	98.31	57.31	62.21	4.90
61.50	98.38	57.47	62.14	4.67
62.00	98.45	57.62	62.07	4.45

TRANSMITTER ANTENNA HEIGHT = 1Ø.ØØ FT
TRANSMITTER ERP = 1ØØ.ØØ Watts
COMMUNICATION RECEIVER LOSS = 2.ØØ dB
COMMUNICATION RECEIVER ANTENNA GAIN IN THE DIRECTION OF THE TRANSMITTER = 3.ØØ
COMMUNICATION RECEIVER ANTENNA HEIGHT = 1Ø.ØØ FT
INTERCEPT RECEIVER ANTENNA HEIGHT = 6Ø.ØØ FT
SNR REQUIRED AT THE COMMUNICATION RECEIVER INPUT = 13.ØØ
QNR REQUIRED AT THE INTERCEPT RECEIVER INPUT = 1Ø.ØØ
ANTENNA POLARIZATION IS V
FREQUENCY = 5Ø.ØØ MHz
TRANSMITTER ANTENNA GAIN IN THE DIRECTION OF THE COMMUNICATION LINK RECEIVER = 3.ØØ
TRANSMITTER ANTENNA GAIN IN THE DIRECTION OF THE INTERCEPT RECEIVER ANTENNA = 1.ØØ
INTERCEPT RECEIVER ANTENNA GAIN IN THE DIRECTION OF THE TRANSMITTER ANTENNA = 6.ØØ
INTERCEPT RECEIVER TIME-BANDWIDTH PRODUCT = 1ØØØ.ØØ
TRANSMISSION LINE LOSSES = Ø.5Ø dB
CONDUCTIVITY = Ø.Ø2 mho/m
PERMITTIVITY = 25.ØØ
INTERCEPT RECEIVER NOISE FIGURE = 6.ØØ dB
COMMUNICATION RECEIVER RESOLUTION BANDWIDTH = 25ØØØ.ØØ Hz
SPREAD SPECTRUM BANDWIDTH = 1ØØ.ØØ MHz
INTERCEPT RECEIVER RESOLUTION BANDWIDTH = 25ØØØ.ØØ Hz
INTERCEPT RECEIVER LOSS = 2.ØØ MHz
COMMUNICATION RECEIVER NOISE FIGURE = 1Ø.ØØ dB
SURFACE REFRACTIVITY COEFFICIENT = 3ØØ.ØØ
TERRAIN PARAMETER DELTA = 2ØØ.ØØ

COMMUNICATIONS RECEIVER DATA HAS BEEN CHOSEN

DUE TO THE REQUIRED SNR OF 13.ØØ dB AT THE RECEIVER INPUT
A RECEIVER SENSITIVITY OF -1Ø7.Ø2 dBm IS NEEDED

******* COMMUNICATIONS FREQ=5Ø MHz *******

Distance (miles)	Free Space Losses (dB)	Excess Losses (dB)	Signal-to-Receiver Sensitivity: Free Space R-Squared Propagation (dB above Receiver Sensitivity)	Ground R-Squared Propagation	Ground R-Fourth Propagation
Ø.5Ø	64.54	39.46	95.98	56.52	58.41
1.ØØ	7Ø.56	39.66	89.96	5Ø.3Ø	46.17
1.5Ø	74.Ø8	39.85	86.44	46.59	38.93
2.ØØ	76.58	4Ø.Ø4	83.94	43.89	33.74
2.5Ø	78.52	4Ø.24	82.ØØ	41.76	29.67
3.ØØ	8Ø.1Ø	4Ø.43	8Ø.42	39.98	26.31
3.5Ø	81.44	4Ø.63	79.Ø8	38.45	23.44
4.ØØ	82.6Ø	4Ø.82	77.92	37.1Ø	2Ø.92
4.5Ø	83.63	41.Ø1	76.89	35.88	18.68
5.ØØ	84.54	41.21	75.98	34.77	16.66
5.5Ø	85.37	41.4Ø	75.15	33.75	14.81
6.ØØ	86.13	41.6Ø	74.4Ø	32.8Ø	13.1Ø
6.5Ø	86.82	41.79	73.7Ø	31.91	11.52

7.00	87.46	41.99	73.06	31.07	10.04
7.50	88.06	42.18	72.46	30.28	8.64
8.00	88.62	42.37	71.90	29.52	7.33
8.50	89.15	42.57	71.37	28.80	6.08
9.00	89.65	42.76	70.87	28.11	4.89
9.50	90.12	42.96	70.40	27.45	3.76
10.00	90.56	43.15	69.96	26.81	2.67
10.50	90.99	43.35	69.53	26.19	1.63
11.00	91.39	43.54	69.13	25.59	0.63
11.50	91.78	43.73	68.74	25.01	
12.00	92.15	43.93	68.37	24.45	
12.50	92.50	44.12	68.02	23.90	
13.00	92.84	44.32	67.68	23.36	
13.50	93.17	44.51	67.35	22.84	
14.00	93.48	44.71	67.04	22.33	
14.50	93.79	44.90	66.73	21.83	
15.00	94.08	45.09	66.44	21.34	
15.50	94.37	45.29	66.15	20.86	
16.00	94.64	45.48	65.88	20.39	
16.50	94.91	45.68	65.61	19.93	
17.00	95.17	45.87	65.35	19.48	
17.50	95.42	46.07	65.10	19.03	
18.00	95.67	46.26	64.85	18.59	
18.50	95.91	46.45	64.61	18.16	
19.00	96.14	46.65	64.38	17.73	
19.50	96.36	46.84	64.16	17.31	
20.00	96.58	47.04	63.94	16.90	
20.50	96.80	47.23	63.72	16.49	
21.00	97.01	47.43	63.51	16.09	
21.50	97.21	47.62	63.31	15.69	
22.00	97.41	47.81	63.11	15.30	
22.50	97.61	48.01	62.91	14.91	
23.00	97.80	48.20	62.72	14.52	
23.50	97.98	48.40	62.54	14.14	
24.00	98.17	48.59	62.35	13.76	
24.50	98.35	48.79	62.17	13.39	
25.00	98.52	48.98	62.00	13.02	
25.50	98.69	49.17	61.83	12.65	
26.00	98.86	49.37	61.66	12.29	
26.50	99.03	49.56	61.49	11.93	
27.00	99.19	49.76	61.33	11.57	
27.50	99.35	49.95	61.17	11.22	
28.00	99.51	50.14	61.02	10.87	
28.50	99.66	50.34	60.86	10.52	
29.00	99.81	50.53	60.71	10.18	
29.50	99.96	50.73	60.56	9.83	
30.00	100.10	50.92	60.42	9.49	
30.50	100.25	51.12	60.27	9.16	
31.00	100.39	51.31	60.13	8.82	
31.50	100.53	51.50	59.99	8.49	
32.00	100.67	51.70	59.86	8.16	
32.50	100.80	51.89	59.72	7.83	
33.00	100.93	52.09	59.59	7.50	
33.50	101.06	52.28	59.46	7.18	
34.00	101.19	52.48	59.33	6.85	
34.50	101.32	52.67	59.20	6.53	
35.00	101.44	52.86	59.08	6.21	
35.50	101.57	53.06	58.95	5.89	
36.00	101.69	53.25	58.83	5.58	
36.50	101.81	53.45	58.71	5.27	
37.00	101.93	53.64	58.59	4.95	

37.50	102.04	53.84	58.48	4.64
38.00	102.16	54.03	58.36	4.33
38.50	102.27	54.22	58.25	4.02
39.00	102.38	54.42	58.14	3.72
39.50	102.49	54.61	58.03	3.41
40.00	102.60	54.81	57.92	3.11
40.50	102.71	55.00	57.81	2.81
41.00	102.82	55.20	57.70	2.51
41.50	102.92	55.39	57.60	2.21
42.00	103.03	55.58	57.49	1.91
42.50	103.13	55.78	57.39	1.61
43.00	103.23	55.97	57.29	1.32
43.50	103.33	56.17	57.19	1.02
44.00	103.43	56.36	57.09	0.73
44.50	103.53	56.56	56.99	0.44
45.00	103.63	56.75	56.89	0.14
45.50	103.72	56.94	56.80	

TRANSMITTER ANTENNA HEIGHT = 10.00 FT
TRANSMITTER ERP = 100.00 Watts
COMMUNICATION RECEIVER LOSS = 2.00 dB
COMMUNICATION RECEIVER ANTENNA GAIN IN THE DIRECTION OF THE TRANSMITTER = 3.00
COMMUNICATION RECEIVER ANTENNA HEIGHT = 10.00 FT
INTERCEPT RECEIVER ANTENNA HEIGHT = 60.00 FT
SNR REQUIRED AT THE COMMUNICATION RECEIVER INPUT = 13.00
QNR REQUIRED AT THE INTERCEPT RECEIVER INPUT = 10.00
ANTENNA POLARIZATION IS V
FREQUENCY = 100.00 MHz
TRANSMITTER ANTENNA GAIN IN THE DIRECTION OF THE COMMUNICATION LINK RECEIVER = 3.00
TRANSMITTER ANTENNA GAIN IN THE DIRECTION OF THE INTERCEPT RECEIVER ANTENNA = 1.00
INTERCEPT RECEIVER ANTENNA GAIN IN THE DIRECTION OF THE TRANSMITTER ANTENNA = 6.00
INTERCEPT RECEIVER TIME-BANDWIDTH PRODUCT = 1000.00
TRANSMISSION LINE LOSSES = 0.50 dB
CONDUCTIVITY = 0.02 mho/m
PERMITTIVITY = 25.00
INTERCEPT RECEIVER NOISE FIGURE = 6.00 dB
COMMUNICATION RECEIVER RESOLUTION BANDWIDTH = 25000.00 Hz
SPREAD SPECTRUM BANDWIDTH = 100.00 MHz
INTERCEPT RECEIVER RESOLUTION BANDWIDTH = 25000.00 Hz
INTERCEPT RECEIVER LOSS = 2.00 MHz
COMMUNICATION RECEIVER NOISE FIGURE = 10.00 dB
SURFACE REFRACTIVITY COEFFICIENT = 300.00
TERRAIN PARAMETER DELTA - 200.00

COMMUNICATIONS RECEIVER DATA HAS BEEN CHOSEN

DUE TO THE REQUIRED SNR OF 13.00 dB AT THE RECEIVER INPUT
A RECEIVER SENSITIVITY OF -107.02 dBm IS NEEDED

****** COMMUNICATIONS FREQ=100 MHz *******

Distance	Free Space Losses	Excess Losses	Signal-to-Receiver Sensitivity: Free Space R-Squared Propagation	Ground R-Squared Propagation	Ground R-Fourth Propagation
(miles)	(dB)	(dB)	(dB above Receiver Sensitivity)		
0.50	70.56	38.68	89.96	51.28	53.16
1.00	76.58	38.91	83.94	45.03	40.90
1.50	80.10	39.13	80.42	41.29	33.63
2.00	82.60	39.35	77.92	38.57	28.41
2.50	84.54	39.58	75.98	36.40	24.31
3.00	86.13	39.80	74.40	34.60	20.92
3.50	87.46	40.02	73.06	33.03	18.02
4.00	88.62	40.25	71.90	31.65	15.48
4.50	89.65	40.47	70.87	30.40	13.21
5.00	90.56	40.69	69.96	29.27	11.15
5.50	91.39	40.92	69.13	28.21	9.27
6.00	92.15	41.14	68.37	27.24	7.54
6.50	92.84	41.36	67.68	26.32	5.93

7.00	93.48	41.59	67.04	25.45	4.42
7.50	94.08	41.81	66.44	24.63	2.99
8.00	94.64	42.03	65.88	23.84	1.65
8.50	95.17	42.26	65.35	23.09	0.37
9.00	95.67	42.48	64.85	22.37	
9.50	96.14	42.70	64.38	21.68	
10.00	96.58	42.93	63.94	21.01	
10.50	97.01	43.15	63.51	20.36	
11.00	97.41	43.37	63.11	19.74	
11.50	97.80	43.60	62.72	19.13	
12.00	98.17	43.82	62.35	18.53	
12.50	98.52	44.04	62.00	17.96	
13.00	98.86	44.27	61.66	17.39	
13.50	99.19	44.49	61.33	16.84	
14.00	99.51	44.71	61.02	16.30	
14.50	99.81	44.94	60.71	15.77	
15.00	100.10	45.16	60.42	15.26	
15.50	100.39	45.38	60.13	14.75	
16.00	100.67	45.61	59.86	14.25	
16.50	100.93	45.83	59.59	13.76	
17.00	101.19	46.05	59.33	13.28	
17.50	101.44	46.28	59.08	12.80	
18.00	101.69	46.50	58.83	12.33	
18.50	101.93	46.72	58.59	11.87	
19.00	102.16	46.95	58.36	11.42	
19.50	102.38	47.17	58.14	10.97	
20.00	102.60	47.39	57.92	10.52	
20.50	102.82	47.62	57.70	10.09	
21.00	103.03	47.84	57.49	9.65	
21.50	103.23	48.06	57.29	9.23	
22.00	103.43	48.29	57.09	8.80	
22.50	103.63	48.51	56.89	8.38	
23.00	103.82	48.73	56.70	7.97	
23.50	104.00	48.96	56.52	7.56	
24.00	104.19	49.18	56.33	7.15	
24.50	104.37	49.40	56.15	6.75	
25.00	104.54	49.63	55.98	6.35	
25.50	104.71	49.85	55.81	5.96	
26.00	104.88	50.07	55.64	5.56	
26.50	105.05	50.30	55.47	5.18	
27.00	105.21	50.52	55.31	4.79	
27.50	105.37	50.74	55.15	4.41	
28.00	105.53	50.97	54.99	4.03	
28.50	105.68	51.19	54.84	3.65	
29.00	105.83	51.41	54.69	3.28	
29.50	105.98	51.64	54.54	2.90	
30.00	106.13	51.86	54.40	2.53	
30.50	106.27	52.08	54.25	2.17	
31.00	106.41	52.31	54.11	1.80	
31.50	106.55	52.53	53.97	1.44	
32.00	106.69	52.75	53.83	1.08	
32.50	106.82	52.98	53.70	0.72	
33.00	106.95	53.20	53.57	0.37	
33.50	107.08	53.42	53.44	0.01	
34.00	107.21	53.65	53.31		

TRANSMITTER ANTENNA HEIGHT = 10.00 FT
TRANSMITTER ERP = 100.00 Watts
COMMUNICATION RECEIVER LOSS = 2.00 dB
COMMUNICATION RECEIVER ANTENNA GAIN IN THE DIRECTION OF THE TRANSMITTER = 3.00
COMMUNICATION RECEIVER ANTENNA HEIGHT = 10.00 FT
INTERCEPT RECEIVER ANTENNA HEIGHT = 60.00 FT
SNR REQUIRED AT THE COMMUNICATION RECEIVER INPUT = 13.00
QNR REQUIRED AT THE INTERCEPT RECEIVER INPUT = 10.00
ANTENNA POLARIZATION IS V
FREQUENCY = 300.00 MHz
TRANSMITTER ANTENNA GAIN IN THE DIRECTION OF THE COMMUNICATION LINK RECEIVER = 3.00
TRANSMITTER ANTENNA GAIN IN THE DIRECTION OF THE INTERCEPT RECEIVER ANTENNA = 1.00
INTERCEPT RECEIVER ANTENNA GAIN IN THE DIRECTION OF THE TRANSMITTER ANTENNA = 6.00
INTERCEPT RECEIVER TIME-BANDWIDTH PRODUCT = 1000.00
TRANSMISSION LINE LOSSES = 0.50 dB
CONDUCTIVITY = 0.02 mho/m
PERMITTIVITY = 25.00
INTERCEPT RECEIVER NOISE FIGURE = 6.00 dB
COMMUNICATION RECEIVER RESOLUTION BANDWIDTH = 25000.00 Hz
SPREAD SPECTRUM BANDWIDTH = 100.00 MHz
INTERCEPT RECEIVER RESOLUTION BANDWIDTH = 25000.00 Hz
INTERCEPT RECEIVER LOSS = 2.00 MHz
COMMUNICATION RECEIVER NOISE FIGURE = 10.00 dB
SURFACE REFRACTIVITY COEFFICIENT = 300.00
TERRAIN PARAMETER DELTA = 200.00

COMMUNICATIONS RECEIVER DATA HAS BEEN CHOSEN

DUE TO THE REQUIRED SNR OF 13.00 dB AT THE RECEIVER INPUT
A RECEIVER SENSITIVITY OF -107.02 dBm IS NEEDED

****** COMMUNICATIONS FREQ=300 MHz *******

Distance (miles)	Free Space Losses (dB)	Excess Losses (dB)	Signal-to-Receiver Sensitivity: Free Space R-Squared Propagation (dB above Receiver Sensitivity)	Ground R-Squared Propagation	Ground R-Fourth Propagation
0.50	80.10	36.81	80.42	43.61	45.50
1.00	86.13	37.07	74.40	37.33	33.19
1.50	89.65	37.33	70.87	33.54	25.89
2.00	92.15	37.59	68.37	30.78	20.63
2.50	94.08	37.85	66.44	28.58	16.49
3.00	95.67	38.12	64.85	26.74	13.06
3.50	97.01	38.38	63.51	25.13	10.12
4.00	98.17	38.64	62.35	23.71	7.54
4.50	99.19	38.90	61.33	22.43	5.23
5.00	100.10	39.17	60.42	21.25	3.14
5.50	100.93	39.43	59.59	20.16	1.22
6.00	101.69	39.69	58.83	19.14	
6.50	102.38	39.95	58.14	18.19	

7.00	103.03	40.21	57.49	17.28
7.50	103.63	40.48	56.89	16.42
8.00	104.19	40.74	56.33	15.60
8.50	104.71	41.00	55.81	14.81
9.00	105.21	41.26	55.31	14.05
9.50	105.68	41.52	54.84	13.32
10.00	106.13	41.79	54.40	12.61
10.50	106.55	42.05	53.97	11.92
11.00	106.95	42.31	53.57	11.26
11.50	107.34	42.57	53.18	10.61
12.00	107.71	42.83	52.81	9.98
12.50	108.06	43.10	52.46	9.36
13.00	108.40	43.36	52.12	8.76
13.50	108.73	43.62	51.79	8.17
14.00	109.05	43.88	51.47	7.59
14.50	109.35	44.15	51.17	7.02
15.00	109.65	44.41	50.87	6.47
15.50	109.93	44.67	50.59	5.92
16.00	110.21	44.93	50.31	5.38
16.50	110.48	45.19	50.05	4.85
17.00	110.73	45.46	49.79	4.33
17.50	110.99	45.72	49.53	3.82
18.00	111.23	45.98	49.29	3.31
18.50	111.47	46.24	49.05	2.81
19.00	111.70	46.50	48.82	2.32
19.50	111.93	46.77	48.59	1.83
20.00	112.15	47.03	48.37	1.35
20.50	112.36	47.29	48.16	0.87
21.00	112.57	47.55	47.95	0.40
21.50	112.77	47.81	47.75	

TRANSMITTER ANTENNA HEIGHT = 10.00 FT
TRANSMITTER ERP = 100.00 Watts
COMMUNICATION RECEIVER LOSS = 2.00 dB
COMMUNICATION RECEIVER ANTENNA GAIN IN THE DIRECTION OF THE TRANSMITTER = 3.00
COMMUNICATION RECEIVER ANTENNA HEIGHT = 10.00 FT
INTERCEPT RECEIVER ANTENNA HEIGHT = 60.00 FT
SNR REQUIRED AT THE COMMUNICATION RECEIVER INPUT = 13.00
QNR REQUIRED AT THE INTERCEPT RECEIVER INPUT = 10.00
ANTENNA POLARIZATION IS V
FREQUENCY = 500.00 MHz
TRANSMITTER ANTENNA GAIN IN THE DIRECTION OF THE COMMUNICATION LINK RECEIVER = 3.00
TRANSMITTER ANTENNA GAIN IN THE DIRECTION OF THE INTERCEPT RECEIVER ANTENNA = 1.00
INTERCEPT RECEIVER ANTENNA GAIN IN THE DIRECTION OF THE TRANSMITTER ANTENNA = 6.00
INTERCEPT RECEIVER TIME-BANDWIDTH PRODUCT = 1000.00
TRANSMISSION LINE LOSSES = 0.50 dB
CONDUCTIVITY = 0.02 mho/m
PERMITTIVITY = 25.00
INTERCEPT RECEIVER NOISE FIGURE = 6.00 dB
COMMUNICATION RECEIVER RESOLUTION BANDWIDTH = 25000.00 Hz
SPREAD SPECTRUM BANDWIDTH = 100.00 MHz
INTERCEPT RECEIVER RESOLUTION BANDWIDTH = 25000.00 Hz
INTERCEPT RECEIVER LOSS = 2.00 MHz
COMMUNICATION RECEIVER NOISE FIGURE = 10.00 dB
SURFACE REFRACTIVITY COEFFICIENT = 300.00
TERRAIN PARAMETER DELTA = 200.00

COMMUNICATIONS RECEIVER DATA HAS BEEN CHOSEN

DUE TO THE REQUIRED SNR OF 13.00 dB AT THE RECEIVER INPUT
A RECEIVER SENSITIVITY OF -107.02 dBm IS NEEDED

******* COMMUNICATIONS FREQ=500 MHz ********

Distance (miles)	Free Space Losses (dB)	Excess Losses (dB)	Signal-to-Receiver Sensitivity: Free Space R-Squared Propagation	Ground R-Squared Propagation	Ground R-Fourth Propagation
			(dB above Receiver Sensitivity)		
0.50	84.54	37.16	75.98	38.82	40.71
1.00	90.56	37.44	69.96	32.52	28.39
1.50	94.08	37.71	66.44	28.72	21.07
2.00	96.58	37.99	63.94	25.95	15.79
2.50	98.52	38.27	62.00	23.73	11.64
3.00	100.10	38.54	60.42	21.87	8.20
3.50	101.44	38.82	59.08	20.26	5.24
4.00	102.60	39.10	57.92	18.82	2.65
4.50	103.63	39.37	56.89	17.52	0.32
5.00	104.54	39.65	55.98	16.33	
5.50	105.37	39.93	55.15	15.22	
6.00	106.13	40.20	54.40	14.19	
6.50	106.82	40.48	53.70	13.22	

7.00	107.46	40.76	53.06	12.30
7.50	108.06	41.03	52.46	11.42
8.00	108.62	41.31	51.90	10.59
8.50	109.15	41.59	51.37	9.78
9.00	109.65	41.86	50.87	9.01
9.50	110.12	42.14	50.40	8.26
10.00	110.56	42.42	49.96	7.54
10.50	110.99	42.69	49.53	6.84
11.00	111.39	42.97	49.13	6.16
11.50	111.78	43.25	48.74	5.50
12.00	112.15	43.52	48.37	4.85
12.50	112.50	43.80	48.02	4.22
13.00	112.84	44.08	47.68	3.60
13.50	113.17	44.35	47.35	3.00
14.00	113.48	44.63	47.04	2.41
14.50	113.79	44.91	46.73	1.82
15.00	114.08	45.18	46.44	1.25
15.50	114.37	45.46	46.15	0.69
16.00	114.64	45.74	45.88	0.14
16.50	114.91	46.01	45.61	

TABULAR DATA FOR GROUND-TO-GROUND (GROUND R-FOURTH) AND AIR-TO-GROUND (GROUND R-SQUARED) INTERCEPT LINK PERFORMANCE AS A FUNCTION OF THE CENTER FREQUENCY OF OPERATION

(for Figures 3.5.b and c, respectively)

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TRANSMITTER ANTENNA HEIGHT =   10.00 FT
TRANSMITTER ERP =   100.00 Watts
COMMUNICATION RECEIVER LOSS =    2.00 dB
COMMUNICATION RECEIVER ANTENNA GAIN IN THE DIRECTION OF THE TRANSMITTER =    3.00
COMMUNICATION RECEIVER ANTENNA HEIGHT =   10.00 FT
INTERCEPT RECEIVER ANTENNA HEIGHT =   60.00 FT
SNR REQUIRED AT THE COMMUNICATION RECEIVER INPUT =   13.00
QNR REQUIRED AT THE INTERCEPT RECEIVER INPUT =   10.00
ANTENNA POLARIZATION IS V
FREQUENCY =  20.00 MHz
TRANSMITTER ANTENNA GAIN IN THE DIRECTION OF THE COMMUNICATION LINK RECEIVER =    3.00
TRANSMITTER ANTENNA GAIN IN THE DIRECTION OF THE INTERCEPT RECEIVER ANTENNA =    1.00
INTERCEPT RECEIVER ANTENNA GAIN IN THE DIRECTION OF THE TRANSMITTER ANTENNA =    6.00
INTERCEPT RECEIVER TIME-BANDWIDTH PRODUCT = 1000.00
TRANSMISSION LINE LOSSES =    0.50 dB
CONDUCTIVITY =    0.02 mho/m
PERMITTIVITY =   25.00
INTERCEPT RECEIVER NOISE FIGURE =    6.00 dB
COMMUNICATION RECEIVER RESOLUTION BANDWIDTH = 25000.00 Hz
SPREAD SPECTRUM BANDWIDTH =  100.00 MHz
INTERCEPT RECEIVER RESOLUTION BANDWIDTH = 25000.00 Hz
INTERCEPT RECEIVER LOSS =    2.00 MHz
COMMUNICATION RECEIVER NOISE FIGURE =   10.00 dB
SURFACE REFRACTIVITY COEFFICIENT =  300.00
TERRAIN PARAMETER DELTA =  200.00


INTERCEPT RECEIVER DATA HAS BEEN CHOSEN


DUE TO THE REQUIRED SNR OF   10.00 dB AT THE RECEIVER INPUT
A RECEIVER SENSITIVITY OF  -78.00 dBm IS NEEDED


***** INTERCEPT FREQ=20 MHZ  *****
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Distance (miles)	Free Space Losses (dB)	Excess Losses (dB)	Signal-to-Receiver Sensitivity: Free Space R-Squared Propagation (dB above Receiver Sensitivity)	Ground R-Squared Propagation	Ground R-Fourth Propagation
0.50	56.58	35.65	75.92	40.27	42.16
0.80	60.67	35.74	71.83	36.10	33.90
1.10	63.43	35.82	69.07	33.24	28.28
1.40	65.53	35.91	66.97	31.06	24.01
1.70	67.21	36.00	65.29	29.29	20.55
2.00	68.62	36.09	63.88	27.79	17.63
2.30	69.84	36.18	62.66	26.49	15.12
2.60	70.90	36.26	61.60	25.33	12.90
2.90	71.85	36.35	60.65	24.30	10.92
3.20	72.71	36.44	59.79	23.35	9.12
3.50	73.48	36.53	59.02	22.49	7.47
3.80	74.20	36.62	58.30	21.68	5.96
4.10	74.86	36.70	57.64	20.94	4.55

4.40	75.47	36.79	57.03	20.23	3.23
4.70	76.05	36.88	56.45	19.57	2.00
5.00	76.58	36.97	55.92	18.95	0.84
5.30	77.09	37.06	55.41	18.35	
5.60	77.57	37.15	54.93	17.79	
5.90	78.02	37.23	54.48	17.25	
6.20	78.45	37.32	54.05	16.73	
6.50	78.86	37.41	53.64	16.23	
6.80	79.25	37.50	53.25	15.75	
7.10	79.63	37.59	52.87	15.29	
7.40	79.99	37.67	52.51	14.84	
7.70	80.33	37.76	52.17	14.40	
8.00	80.67	37.85	51.83	13.98	
8.30	80.99	37.94	51.51	13.58	
8.60	81.29	38.03	51.21	13.18	
8.90	81.59	38.11	50.91	12.79	
9.20	81.88	38.20	50.62	12.42	
9.50	82.16	38.29	50.34	12.05	
9.80	82.43	38.38	50.07	11.69	
10.10	82.69	38.47	49.81	11.34	
10.40	82.94	38.56	49.56	11.00	
10.70	83.19	38.64	49.31	10.67	
11.00	83.43	38.73	49.07	10.34	
11.30	83.67	38.82	48.83	10.02	
11.60	83.89	38.91	48.61	9.70	
11.90	84.11	39.00	48.39	9.39	
12.20	84.33	39.08	48.17	9.09	
12.50	84.54	39.17	47.96	8.79	
12.80	84.75	39.26	47.75	8.49	
13.10	84.95	39.35	47.55	8.20	
13.40	85.15	39.44	47.35	7.92	
13.70	85.34	39.52	47.16	7.64	
14.00	85.53	39.61	46.97	7.36	
14.30	85.71	39.70	46.79	7.09	
14.60	85.89	39.79	46.61	6.82	
14.90	86.07	39.88	46.43	6.56	
15.20	86.24	39.97	46.26	6.29	
15.50	86.41	40.05	46.09	6.04	
15.80	86.58	40.14	45.92	5.78	
16.10	86.74	40.23	45.76	5.53	
16.40	86.90	40.32	45.60	5.28	
16.70	87.06	40.41	45.44	5.04	
17.00	87.21	40.49	45.29	4.79	
17.30	87.36	40.58	45.14	4.55	
17.60	87.51	40.67	44.99	4.32	
17.90	87.66	40.76	44.84	4.08	
18.20	87.81	40.85	44.69	3.85	
18.50	87.95	40.93	44.55	3.62	
18.80	88.09	41.02	44.41	3.39	
19.10	88.22	41.11	44.28	3.17	
19.40	88.36	41.20	44.14	2.94	
19.70	88.49	41.29	44.01	2.72	
20.00	88.62	41.38	43.88	2.50	
20.30	88.75	41.46	43.75	2.28	
20.60	88.88	41.55	43.62	2.07	
20.90	89.01	41.64	43.49	1.85	
21.20	89.13	41.73	43.37	1.64	
21.50	89.25	41.82	43.25	1.43	
21.80	89.37	41.90	43.13	1.22	
22.10	89.49	41.99	43.01	1.02	
22.40	89.61	42.08	42.89	0.81	
22.70	89.72	42.17	42.78	0.61	
23.00	89.84	42.26	42.66	0.41	
23.30	89.95	42.34	42.55	0.20	
23.60	[illegible]	42.43	42.44	0.00	
23.90	[illegible]	[illegible]	[illegible]		

TRANSMITTER ANTENNA HEIGHT = 10.00 FT
TRANSMITTER ERP = 100.00 Watts
COMMUNICATION RECEIVER LOSS = 2.00 dB
COMMUNICATION RECEIVER ANTENNA GAIN IN THE DIRECTION OF THE TRANSMITTER = 3.00
COMMUNICATION RECEIVER ANTENNA HEIGHT = 10.00 FT
INTERCEPT RECEIVER ANTENNA HEIGHT = 60.00 FT
SNR REQUIRED AT THE COMMUNICATION RECEIVER INPUT = 13.00
SNR REQUIRED AT THE INTERCEPT RECEIVER INPUT = 10.00
ANTENNA POLARIZATION IS V
FREQUENCY = 50.00 MHz
TRANSMITTER ANTENNA GAIN IN THE DIRECTION OF THE COMMUNICATION LINK RECEIVER = 3.00
TRANSMITTER ANTENNA GAIN IN THE DIRECTION OF THE INTERCEPT RECEIVER ANTENNA = 1.00
INTERCEPT RECEIVER ANTENNA GAIN IN THE DIRECTION OF THE TRANSMITTER ANTENNA = 6.00
INTERCEPT RECEIVER TIME BANDWIDTH PRODUCT = 1000.00
TRANSMISSION LINE LOSSES = 0.50 dB
CONDUCTIVITY = 0.02 mho/m
PERMITTIVITY = 25.00
INTERCEPT RECEIVER NOISE FIGURE = 6.00 dB
COMMUNICATION RECEIVER RESOLUTION BANDWIDTH = 25000.00 Hz
SPREAD SPECTRUM BANDWIDTH = 100.00 MHz
INTERCEPT RECEIVER RESOLUTION BANDWIDTH = 25000.00 Hz
INTERCEPT RECEIVER LOSS = 2.00 MHz
COMMUNICATION RECEIVER NOISE FIGURE = 10.00 dB
SURFACE REFRACTIVITY COEFFICIENT = 300.00
TERRAIN PARAMETER DELTA = 200.00

INTERCEPT RECEIVER DATA HAS BEEN CHOSEN

DUE TO THE REQUIRED SNR OF 10.00 dB AT THE RECEIVER INPUT
A RECEIVER SENSITIVITY OF -78.00 dBm IS NEEDED

***** INTERCEPT FREQ-50 MHZ *****

Distance	Free Space Losses	Excess Losses	Signal-to-Receiver Sensitivity: Free Space R-Squared Propagation	Ground R-Squared Propagation	Ground R-Fourth Propagation
(miles)	(dB)	(dB)	(dB above Receiver Sensitivity)		
0.50	64.54	34.20	67.96	33.76	35.65
0.80	68.62	34.31	63.88	29.57	27.37
1.10	71.39	34.42	61.11	26.69	21.73
1.40	73.48	34.53	59.02	24.49	17.43
1.70	75.17	34.64	57.33	22.69	13.95
2.00	76.58	34.75	55.92	21.17	11.02
2.30	77.80	34.86	54.70	19.85	8.48
2.60	78.86	34.97	53.64	18.67	6.24
2.90	79.81	35.08	52.69	17.61	4.23
3.20	80.67	35.19	51.83	16.65	2.41
3.50	81.44	35.30	51.06	15.76	0.75
3.80	82.16	35.41	50.34	14.94	
4.10	82.82	35.52	49.68	14.17	

4.40	83.43	35.63	49.07	13.44
4.70	84.00	35.74	48.50	12.76
5.00	84.54	35.85	47.96	12.11
5.30	85.05	35.96	47.45	11.50
5.60	85.53	36.07	46.97	10.91
5.90	85.98	36.18	46.52	10.35
6.20	86.41	36.29	46.09	9.80
6.50	86.82	36.39	45.68	9.28
6.80	87.21	36.50	45.29	8.78
7.10	87.59	36.61	44.91	8.30
7.40	87.95	36.72	44.55	7.83
7.70	88.29	36.83	44.21	7.37
8.00	88.62	36.94	43.88	6.93
8.30	88.94	37.05	43.56	6.50
8.60	89.25	37.16	43.25	6.08
8.90	89.55	37.27	42.95	5.68
9.20	89.84	37.38	42.66	5.28
9.50	90.12	37.49	42.38	4.89
9.80	90.39	37.60	42.11	4.51
10.10	90.65	37.71	41.85	4.14
10.40	90.90	37.82	41.60	3.77
10.70	91.15	37.93	41.35	3.42
11.00	91.39	38.04	41.11	3.07
11.30	91.62	38.15	40.88	2.72
11.60	91.85	38.26	40.65	2.39
11.90	92.07	38.37	40.43	2.05
12.20	92.29	38.48	40.21	1.73
12.50	92.50	38.59	40.00	1.41
12.80	92.71	38.70	39.79	1.09
13.10	92.91	38.81	39.59	0.78
13.40	93.10	38.92	39.40	0.47
13.70	93.30	39.03	39.20	0.17
14.00	93.48	39.14	39.02	

```
TRANSMITTER ANTENNA HEIGHT =   10.00 FT
TRANSMITTER ERP =   100.00 Watts
COMMUNICATION RECEIVER LOSS =     2.00 dB
COMMUNICATION RECEIVER ANTENNA GAIN IN THE DIRECTION OF THE TRANSMITTER =    3.00
COMMUNICATION RECEIVER ANTENNA HEIGHT =   10.00 FT
INTERCEPT RECEIVER ANTENNA HEIGHT =   60.00 FT
SNR REQUIRED AT THE COMMUNICATION RECEIVER INPUT =   13.00
QNR REQUIRED AT THE INTERCEPT RECEIVER INPUT =   10.00
ANTENNA POLARIZATION IS V
FREQUENCY = 100.00 MHz
TRANSMITTER ANTENNA GAIN IN THE DIRECTION OF THE COMMUNICATION LINK RECEIVER =    3.00
TRANSMITTER ANTENNA GAIN IN THE DIRECTION OF THE INTERCEPT RECEIVER ANTENNA =    1.00
INTERCEPT RECEIVER ANTENNA GAIN IN THE DIRECTION OF THE TRANSMITTER ANTENNA =    6.00
INTERCEPT RECEIVER TIME-BANDWIDTH PRODUCT = 1000.00
TRANSMISSION LINE LOSSES =    0.50 dB
CONDUCTIVITY =    0.02 mho/m
PERMITTIVITY =   25.00
INTERCEPT RECEIVER NOISE FIGURE =     6.00 dB
COMMUNICATION RECEIVER RESOLUTION BANDWIDTH = 25000.00 Hz
SPREAD SPECTRUM BANDWIDTH =   100.00 MHz
INTERCEPT RECEIVER RESOLUTION BANDWIDTH = 25000.00 Hz
INTERCEPT RECEIVER LOSS =     2.00 MHz
COMMUNICATION RECEIVER NOISE FIGURE =   10.00 dB
SURFACE REFRACTIVITY COEFFICIENT =  300.00
TERRAIN PARAMETER DELTA =  200.00


INTERCEPT RECEIVER DATA HAS BEEN CHOSEN


DUE TO THE REQUIRED SNR OF   10.00 dB AT THE RECEIVER INPUT
A RECEIVER SENSITIVITY OF  -78.00 dBm IS NEEDED


*****  INTERCEPT  FREQ=100 MHZ  *****
```

Distance (miles)	Free Space Losses (dB)	Excess Losses (dB)	Signal-to-Receiver Sensitivity: Free Space R-Squared Propagation (dB above Receiver Sensitivity)	Ground R-Squared Propagation	Ground R-Fourth Propagation
0.50	70.56	32.29	61.94	29.65	31.54
0.80	74.64	32.41	57.86	25.44	23.25
1.10	77.41	32.54	55.09	22.55	17.59
1.40	79.51	32.67	52.99	20.33	13.27
1.70	81.19	32.79	51.31	18.52	9.77
2.00	82.60	32.92	49.90	16.98	6.82
2.30	83.82	33.04	48.68	15.64	4.27
2.60	84.88	33.17	47.62	14.45	2.01
2.90	85.83	33.30	46.67	13.37	
3.20	86.69	33.42	45.81	12.39	
3.50	87.46	33.55	45.04	11.48	
3.80	88.18	33.68	44.32	10.64	
4.10	88.84	33.80	43.66	9.86	

4.4Ø	89.45	33.93	43.Ø5	9.12
4.7Ø	9Ø.Ø2	34.Ø6	42.48	8.42
5.ØØ	9Ø.56	34.18	41.94	7.75
5.3Ø	91.Ø7	34.31	41.43	7.12
5.6Ø	91.55	34.44	4Ø.95	6.52
5.9Ø	92.ØØ	34.56	4Ø.5Ø	5.94
6.2Ø	92.43	34.69	4Ø.Ø7	5.38
6.5Ø	92.84	34.82	39.66	4.84
6.8Ø	93.23	34.94	39.27	4.32
7.1Ø	93.61	35.Ø7	38.89	3.82
7.4Ø	93.97	35.2Ø	38.53	3.34
7.7Ø	94.31	35.32	38.19	2.86
8.ØØ	94.64	35.45	37.86	2.4Ø
8.3Ø	94.96	35.58	37.54	1.96
8.6Ø	95.27	35.7Ø	37.23	1.52
8.9Ø	95.57	35.83	36.93	1.1Ø
9.2Ø	95.86	35.96	36.64	Ø.68
9.5Ø	96.14	36.Ø8	36.36	Ø.28
9.8Ø	96.41	36.21	36.Ø9	

TRANSMITTER ANTENNA HEIGHT = 10.00 FT
TRANSMITTER ERP = 100.00 Watts
COMMUNICATION RECEIVER LOSS = 2.00 dB
COMMUNICATION RECEIVER ANTENNA GAIN IN THE DIRECTION OF THE TRANSMITTER = 3.00
COMMUNICATION RECEIVER ANTENNA HEIGHT = 10.00 FT
INTERCEPT RECEIVER ANTENNA HEIGHT = 60.00 FT
SNR REQUIRED AT THE COMMUNICATION RECEIVER INPUT = 13.00
QNR REQUIRED AT THE INTERCEPT RECEIVER INPUT = 10.00
ANTENNA POLARIZATION IS V
FREQUENCY = 300.00 MHz
TRANSMITTER ANTENNA GAIN IN THE DIRECTION OF THE COMMUNICATION LINK RECEIVER = 3.00
TRANSMITTER ANTENNA GAIN IN THE DIRECTION OF THE INTERCEPT RECEIVER ANTENNA = 1.00
INTERCEPT RECEIVER ANTENNA GAIN IN THE DIRECTION OF THE TRANSMITTER ANTENNA = 6.00
INTERCEPT RECEIVER TIME-BANDWIDTH PRODUCT = 1000.00
TRANSMISSION LINE LOSSES = 0.50 dB
CONDUCTIVITY = 0.02 mho/m
PERMITTIVITY = 25.00
INTERCEPT RECEIVER NOISE FIGURE = 6.00 dB
COMMUNICATION RECEIVER RESOLUTION BANDWIDTH = 25000.00 Hz
SPREAD SPECTRUM BANDWIDTH = 100.00 MHz
INTERCEPT RECEIVER RESOLUTION BANDWIDTH = 25000.00 Hz
INTERCEPT RECEIVER LOSS = 2.00 MHz
COMMUNICATION RECEIVER NOISE FIGURE = 10.00 dB
SURFACE REFRACTIVITY COEFFICIENT = 300.00
TERRAIN PARAMETER DELTA = 200.00

INTERCEPT RECEIVER DATA HAS BEEN CHOSEN

DUE TO THE REQUIRED SNR OF 10.00 dB AT THE RECEIVER INPUT
A RECEIVER SENSITIVITY OF -78.00 dBm IS NEEDED

***** INTERCEPT FREQ-300 MHZ *****

Distance (miles)	Free Space Losses (dB)	Excess Losses (dB)	Signal-to-Receiver Sensitivity: Free Space R-Squared Propagation (dB above Receiver Sensitivity)	Ground R-Squared Propagation	Ground R-Fourth Propagation
0.50	80.10	27.86	52.40	24.53	26.42
0.80	84.19	30.53	48.31	17.79	15.59
1.10	86.95	30.68	45.55	14.87	9.91
1.40	89.05	30.83	43.45	12.62	5.56
1.70	90.73	30.99	41.77	10.78	2.04
2.00	92.15	31.14	40.35	9.21	
2.30	93.36	31.29	39.14	7.85	
2.60	94.42	31.45	38.08	6.63	
2.90	95.37	31.60	37.13	5.53	
3.20	96.23	31.75	36.27	4.52	
3.50	97.01	31.91	35.49	3.59	
3.80	97.72	32.06	34.78	2.72	
4.10	98.38	32.21	34.12	1.91	
4.40	98.99	32.36	33.51	1.14	
4.70	99.57	32.52	32.93	0.41	
5.00	100.10	32.67	32.40		

```
TRANSMITTER ANTENNA HEIGHT =   10.00 FT
TRANSMITTER ERP =   100.00 Watts
COMMUNICATION RECEIVER LOSS =    2.00 dB
COMMUNICATION RECEIVER ANTENNA GAIN IN THE DIRECTION OF THE TRANSMITTER =    3.00
COMMUNICATION RECEIVER ANTENNA HEIGHT =   10.00 FT
INTERCEPT RECEIVER ANTENNA HEIGHT =   60.00 FT
SNR REQUIRED AT THE COMMUNICATION RECEIVER INPUT =   13.00
QNR REQUIRED AT THE INTERCEPT RECEIVER INPUT =   10.00
ANTENNA POLARIZATION IS V
FREQUENCY = 500.00 MHz
TRANSMITTER ANTENNA GAIN IN THE DIRECTION OF THE COMMUNICATION LINK RECEIVER =    3.00
TRANSMITTER ANTENNA GAIN IN THE DIRECTION OF THE INTERCEPT RECEIVER ANTENNA =    1.00
INTERCEPT RECEIVER ANTENNA GAIN IN THE DIRECTION OF THE TRANSMITTER ANTENNA =    6.00
INTERCEPT RECEIVER TIME-BANDWIDTH PRODUCT = 1000.00
TRANSMISSION LINE LOSSES =    0.50 dB
CONDUCTIVITY =    0.02 mho/m
PERMITTIVITY =   25.00
INTERCEPT RECEIVER NOISE FIGURE =    6.00 dB
COMMUNICATION RECEIVER RESOLUTION BANDWIDTH = 25000.00 Hz
SPREAD SPECTRUM BANDWIDTH =  100.00 MHz
INTERCEPT RECEIVER RESOLUTION BANDWIDTH = 25000.00 Hz
INTERCEPT RECEIVER LOSS =    2.00 MHz
COMMUNICATION RECEIVER NOISE FIGURE =   10.00 dB
SURFACE REFRACTIVITY COEFFICIENT =  300.00
TERRAIN PARAMETER DELTA =  200.00
```

INTERCEPT RECEIVER DATA HAS BEEN CHOSEN

DUE TO THE REQUIRED SNR OF   10.00 dB AT THE RECEIVER INPUT
A RECEIVER SENSITIVITY OF -78.00 dBm IS NEEDED

***** INTERCEPT FREQ-500 MHZ *****

Distance (miles)	Free Space Losses (dB)	Excess Losses (dB)	Signal-to-Receiver Sensitivity: Free Space R-Squared Propagation (dB above Receiver Sensitivity)	Ground R-Squared Propagation	Ground R-Fourth Propagation
0.50	84.54	24.56	47.96	23.40	25.29
0.80	88.62	30.02	43.88	13.86	11.66
1.10	91.39	31.06	41.11	10.05	5.09
1.40	93.48	31.22	39.02	7.79	0.74
1.70	95.17	31.39	37.33	5.94	
2.00	96.58	31.55	35.92	4.36	
2.30	97.80	31.72	34.70	2.98	
2.60	98.86	31.88	33.64	1.75	
2.90	99.81	32.05	32.69	0.64	
3.20	100.67	32.22	31.83		

TABULAR DATA FOR GROUND-TO-GROUND (GROUND R-FOURTH)
AND AIR-TO-GROUND (GROUND R-SQUARED) INTERCEPT LINK
PERFORMANCE AS A FUNCTION OF THE DSE BANDWIDTH
(for Figures 3.6.a and b respectively)

TRANSMITTER ANTENNA HEIGHT = 10.00 FT
TRANSMITTER ERP = 100.00 Watts
COMMUNICATION RECEIVER LOSS = 2.00 dB
COMMUNICATION RECEIVER ANTENNA GAIN IN THE DIRECTION OF THE TRANSMITTER = 3.00
COMMUNICATION RECEIVER ANTENNA HEIGHT = 10.00 FT
INTERCEPT RECEIVER ANTENNA HEIGHT = 60.00 FT
SNR REQUIRED AT THE COMMUNICATION RECEIVER INPUT = 13.00
QNR REQUIRED AT THE INTERCEPT RECEIVER INPUT = 10.00
ANTENNA POLARIZATION IS V
FREQUENCY = 300.00 MHz
TRANSMITTER ANTENNA GAIN IN THE DIRECTION OF THE COMMUNICATION LINK RECEIVER = 3.00
TRANSMITTER ANTENNA GAIN IN THE DIRECTION OF THE INTERCEPT RECEIVER ANTENNA = 1.00
INTERCEPT RECEIVER ANTENNA GAIN IN THE DIRECTION OF THE TRANSMITTER ANTENNA = 6.00
INTERCEPT RECEIVER TIME-BANDWIDTH PRODUCT = 1000.00
TRANSMISSION LINE LOSSES = 0.50 dB
CONDUCTIVITY = 0.02 mho/m
PERMITTIVITY = 25.00
INTERCEPT RECEIVER NOISE FIGURE = 6.00 dB
COMMUNICATION RECEIVER RESOLUTION BANDWIDTH = 25000.00 Hz
SPREAD SPECTRUM BANDWIDTH = 1.00 MHz
INTERCEPT RECEIVER RESOLUTION BANDWIDTH = 25000.00 Hz
INTERCEPT RECEIVER LOSS = 2.00 MHz
COMMUNICATION RECEIVER NOISE FIGURE = 10.00 dB
SURFACE REFRACTIVITY COEFFICIENT = 300.00
TERRAIN PARAMETER DELTA = 200.00

INTERCEPT RECEIVER DATA HAS BEEN CHOSEN

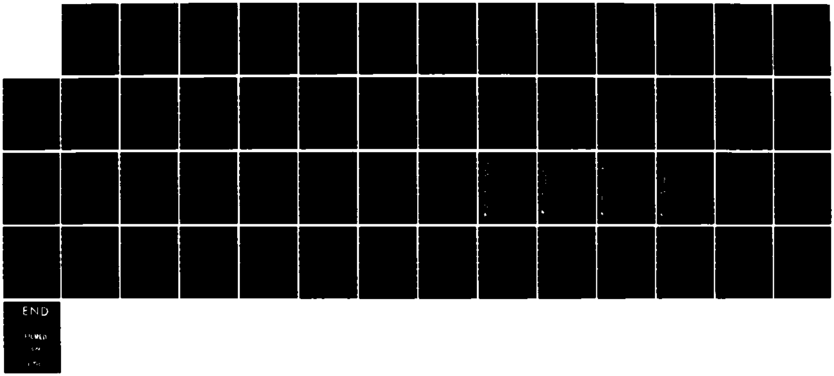
DUE TO THE REQUIRED SNR OF 10.00 dB AT THE RECEIVER INPUT
A RECEIVER SENSITIVITY OF -98.00 dBm IS NEEDED

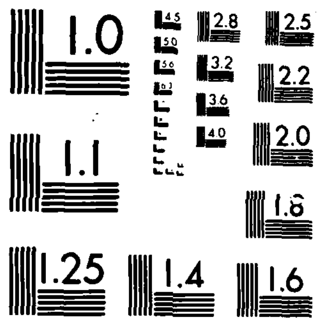
***** INTERCEPT WSS=1 MHz *******

Distance	Free Space Losses	Excess Losses	Signal-to-Receiver Sensitivity: Free Space R-Squared Propagation	Ground R-Squared Propagation	Ground R-Fourth Propagation
(miles)	(dB)	(dB)	(dB above Receiver Sensitivity)		
0.50	80.10	27.86	72.40	44.53	46.42
1.00	86.13	30.63	66.37	35.75	31.61
1.50	89.65	30.88	62.85	31.97	24.31
2.00	92.15	31.14	60.35	29.21	19.06
2.50	94.08	31.39	58.42	27.02	14.93
3.00	95.67	31.65	56.83	25.18	11.51
3.50	97.01	31.91	55.49	23.59	8.57
4.00	98.17	32.16	54.33	22.17	6.00
4.50	99.19	32.42	53.31	20.89	3.70
5.00	100.10	32.67	52.40	19.72	1.61
5.50	100.93	32.93	51.57	18.64	
6.00	101.69	33.18	50.81	17.63	
6.50	102.38	33.44	50.12	16.68	

7.00	103.03	33.69	49.47	15.78
7.50	103.63	33.95	48.87	14.93
8.00	104.19	34.20	48.31	14.11
8.50	104.71	34.46	47.79	13.33
9.00	105.21	34.71	47.29	12.58
9.50	105.68	34.97	46.82	11.85
10.00	106.13	35.22	46.37	11.15
10.50	106.55	35.48	45.95	10.47
11.00	106.95	35.73	45.55	9.81
11.50	107.34	35.99	45.16	9.17
12.00	107.71	36.25	44.79	8.55
12.50	108.06	36.50	44.44	7.94
13.00	108.40	36.76	44.10	7.34
13.50	108.73	37.01	43.77	6.76
14.00	109.05	37.27	43.45	6.19
14.50	109.35	37.52	43.15	5.63
15.00	109.65	37.78	42.85	5.08
15.50	109.93	38.03	42.57	4.54
16.00	110.21	38.29	42.29	4.00
16.50	110.48	38.54	42.02	3.48
17.00	110.73	38.80	41.77	2.97
17.50	110.99	39.05	41.51	2.46
18.00	111.23	39.31	41.27	1.96
18.50	111.47	39.56	41.03	1.47
19.00	111.70	39.82	40.80	0.98
19.50	111.93	40.07	40.57	0.50
20.00	112.15	40.33	40.35	0.02
20.50	112.36	40.59	40.14	

AD-A163 985 ON ACHIEVING NETWORK LPI (LINK PARAMETER INTERACTIONS) 3/3
FOR SPREAD SPECTRUM COMMUNICATIONS(U) E-SYSTEMS INC
FAIRFAX VA MELPAR DIV W J O'BRIEN ET AL. OCT 85
UNCLASSIFIED ARO-21611.3-EL DAAG29-84-C-0008 F/G 17/2.1 NL





MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963 A

TRANSMITTER ANTENNA HEIGHT = 10.00 FT
TRANSMITTER ERP = 100.00 Watts
COMMUNICATION RECEIVER LOSS = 2.00 dB
COMMUNICATION RECEIVER ANTENNA GAIN IN THE DIRECTION OF THE TRANSMITTER = 3.00
COMMUNICATION RECEIVER ANTENNA HEIGHT = 10.00 FT
INTERCEPT RECEIVER ANTENNA HEIGHT = 50.00 FT
SNR REQUIRED AT THE COMMUNICATION RECEIVER INPUT = 13.00
QNR REQUIRED AT THE INTERCEPT RECEIVER INPUT = 10.00
ANTENNA POLARIZATION IS V
FREQUENCY = 300.00 MHz
TRANSMITTER ANTENNA GAIN IN THE DIRECTION OF THE COMMUNICATION LINK RECEIVER = 3.00
TRANSMITTER ANTENNA GAIN IN THE DIRECTION OF THE INTERCEPT RECEIVER ANTENNA = 1.00
INTERCEPT RECEIVER ANTENNA GAIN IN THE DIRECTION OF THE TRANSMITTER ANTENNA = 6.00
INTERCEPT RECEIVER TIME-BANDWIDTH PRODUCT = 1000.00
TRANSMISSION LINE LOSSES = 0.50 dB
CONDUCTIVITY = 0.02 mho/m
PERMITTIVITY = 25.00
INTERCEPT RECEIVER NOISE FIGURE = 6.00 dB
COMMUNICATION RECEIVER RESOLUTION BANDWIDTH = 25000.00 Hz
SPREAD SPECTPUM BANDWIDTH = 10.00 MHz
INTERCEPT RECEIVER RESOLUTION BANDWIDTH = 25000.00 Hz
INTERCEPT RECEIVER LOSS = 2.00 MHz
COMMUNICATION RECEIVER NOISE FIGURE = 10.00 dB
SURFACE REFRACTIVITY COEFFICIENT = 300.00
TERRAIN PARAMETER DELTA = 200.00

INTERCEPT RECEIVER DATA HAS BEEN CHOSEN

DUE TO THE REQUIRED SNR OF 10.00 dB AT THE RECEIVER INPUT
A RECEIVER SENSITIVITY OF -88.00 dBm IS NEEDED

******** INTERCEPT WSS=10 MHz ********

Distance (miles)	Free Space Losses (dB)	Excess Losses (dB)	Signal-to-Receiver Sensitivity: Free Space R-Squared Propagation (dB above Receiver Sensitivity)	Ground R-Squared Propagation	Ground R-Fourth Propagation
0.50	80.10	27.86	62.40	34.53	36.42
1.00	86.13	30.63	56.37	25.75	21.61
1.50	89.65	30.88	52.85	21.97	14.31
2.00	92.15	31.14	50.35	19.21	9.06
2.50	94.08	31.39	48.42	17.02	4.93
3.00	95.67	31.65	46.83	15.18	1.51
3.50	97.01	31.91	45.49	13.59	
4.00	98.17	32.16	44.33	12.17	
4.50	99.19	32.42	43.31	10.89	
5.00	100.10	32.67	42.40	9.72	
5.50	100.93	32.93	41.57	8.64	
6.00	101.69	33.18	40.81	7.63	
6.50	102.38	33.44	40.12	6.68	

7.00	103.03	33.69	39.47	5.78
7.50	103.63	33.95	38.87	4.93
8.00	104.19	34.20	38.31	4.11
8.50	104.71	34.46	37.79	3.33
9.00	105.21	34.71	37.29	2.58
9.50	105.68	34.97	36.82	1.85
10.00	106.13	35.22	36.37	1.15
10.50	106.55	35.48	35.95	0.47
11.00	106.95	35.73	35.55	

```
TRANSMITTER ANTENNA HEIGHT =   10.00 FT
TRANSMITTER ERP =   100.00 Watts
COMMUNICATION RECEIVER LOSS =     2.00 dB
COMMUNICATION RECEIVER ANTENNA GAIN IN THE DIRECTION OF THE TRANSMITTER =     3.00
COMMUNICATION RECEIVER ANTENNA HEIGHT =   10.00 FT
INTERCEPT RECEIVER ANTENNA HEIGHT =   60.00 FT
SNR REQUIRED AT THE COMMUNICATION RECEIVER INPUT =    13.00
ONR REQUIRED AT THE INTERCEPT RECEIVER INPUT =   10.00
ANTENNA POLARIZATION IS V
FREQUENCY = 300.00 MHz
TRANSMITTER ANTENNA GAIN IN THE DIRECTION OF THE COMMUNICATION LINK RECEIVER =     3.00
TRANSMITTER ANTENNA GAIN IN THE DIRECTION OF THE INTERCEPT RECEIVER ANTENNA =    1.00
INTERCEPT RECEIVER ANTENNA GAIN IN THE DIRECTION OF THE TRANSMITTER ANTENNA =    6.00
INTERCEPT RECEIVER TIME-BANDWIDTH PRODUCT = 1000.00
TRANSMISSION LINE LOSSES =    0.50 dB
CONDUCTIVITY =     0.02 mho/m
PERMITTIVITY =    25.00
INTERCEPT RECEIVER NOISE FIGURE =     6.00 dB
COMMUNICATION RECEIVER RESOLUTION BANDWIDTH = 25000.00 Hz
SPREAD SPECTRUM BANDWIDTH =    50.00 MHz
INTERCEPT RECEIVER RESOLUTION BANDWIDTH = 25000.00 Hz
INTERCEPT RECEIVER LOSS =    2.00 MHz
COMMUNICATION RECEIVER NOISE FIGURE =    10.00 dB
SURFACE REFRACTIVITY COEFFICIENT =  300.00
TERRAIN PARAMETER DELTA =  200.00


INTEPCEPT RECEIVER DATA HAS BEEN CHOSEN


DUE TO THE REQUIRED SNP OF   10.00 dB AT THE RECEIVER INPUT
A RECEIVER SENSITIVITY OF  -81.01 dBm IS NEEDED


******* INTERCEPT   WSS=50 MHz  *******
```

Distance (miles)	Free Space Losses (dB)	Excess Losses (dB)	Signal-to-Receiver Sensitivity: Free Space R-Squared Propagation (dB above Receiver Sensitivity)	Ground R-Squared Propagation	Ground R-Fourth Propagation
0.50	80.10	27.86	55.41	27.54	29.43
1.00	86.13	30.63	49.38	18.76	14.62
1.50	89.65	30.88	45.86	14.98	7.32
2.00	92.15	31.14	43.36	12.22	2.07
2.50	94.08	31.39	41.43	10.03	
3.00	95.67	31.65	39.84	8.19	
3.50	97.01	31.91	38.50	6.60	
4.00	98.17	32.16	37.34	5.18	
4.50	99.19	32.42	36.32	3.90	
5.00	100.10	32.67	35.41	2.73	
5.50	100.93	32.93	34.58	1.65	
6.00	101.69	33.18	33.82	0.64	
6.50	102.38	33.44	33.13		

```
TRANSMITTER ANTENNA HEIGHT =   10.00 FT
TRANSMITTER ERP =   100.00 Watts
COMMUNICATION RECEIVER LOSS =    2.00 dB
COMMUNICATION RECEIVER ANTENNA GAIN IN THE DIRECTION OF THE TRANSMITTER =    3.00
COMMUNICATION RECEIVER ANTENNA HEIGHT =   10.00 FT
INTERCEPT RECEIVER ANTENNA HEIGHT =   60.00 FT
SNR REQUIRED AT THE COMMUNICATION RECEIVER INPUT =   13.00
SNR REQUIRED AT THE INTERCEPT RECEIVER INPUT =   10.00
ANTENNA POLARIZATION IS V
FREQUENCY = 300.00 MHz
TRANSMITTER ANTENNA GAIN IN THE DIRECTION OF THE COMMUNICATION LINK RECEIVER =    3.00
TRANSMITTER ANTENNA GAIN IN THE DIRECTION OF THE INTERCEPT RECEIVER ANTENNA =    1.00
INTERCEPT RECEIVER ANTENNA GAIN IN THE DIRECTION OF THE TRANSMITTER ANTENNA =    6.00
INTERCEPT RECEIVER TIME-BANDWIDTH PRODUCT = 1000.00
TRANSMISSION LINE LOSSES =    0.50 dB
CONDUCTIVITY =    0.02 mho/m
PERMITTIVITY =   25.00
INTERCEPT RECEIVER NOISE FIGURE =    6.00 dB
COMMUNICATION RECEIVER RESOLUTION BANDWIDTH = 25000.00 Hz
SPREAD SPECTRUM BANDWIDTH =  100.00 MHz
INTERCEPT RECEIVER RESOLUTION BANDWIDTH = 25000.00 Hz
INTERCEPT RECEIVER LOSS =    2.00 MHz
COMMUNICATION RECEIVER NOISE FIGURE =    10.00 dB
SURFACE REFRACTIVITY COEFFICIENT =  300.00
TERRAIN PARAMETER DELTA =  200.00


INTERCEPT RECEIVER DATA HAS BEEN CHOSEN


DUE TO THE REQUIRED SNR OF   10.00 dB AT THE RECEIVER INPUT
A RECEIVER SENSITIVITY OF  -78.00 dBm IS NEEDED


******* INTERCEPT  WSS=100 MHz  *******
```

Distance (miles)	Free Space Losses (dB)	Excess Losses (dB)	Signal-to-Receiver Sensitivity: Free Space R-Squared Propagation (dB above Receiver Sensitivity)	Ground R-Squared Propagation	Ground R-Fourth Propagation
0.50	80.10	27.86	52.40	24.53	26.42
1.00	86.13	30.63	46.37	15.75	11.61
1.50	89.65	30.88	42.85	11.97	4.31
2.00	92.15	31.14	40.35	9.21	
2.50	94.08	31.39	38.42	7.02	
3.00	95.67	31.65	36.83	5.18	
3.50	97.01	31.91	35.49	3.59	
4.00	98.17	32.16	34.33	2.17	
4.50	99.19	32.42	33.31	0.89	
5.00	100.10	32.67	32.40		

TRANSMITTER ANTENNA HEIGHT = 10.00 FT
TRANSMITTER ERP = 100.00 Watts
COMMUNICATION RECEIVER LOSS = 2.00 dB
COMMUNICATION RECEIVER ANTENNA GAIN IN THE DIRECTION OF THE TRANSMITTER = 3.00
COMMUNICATION RECEIVER ANTENNA HEIGHT = 10.00 FT
INTERCEPT RECEIVER ANTENNA HEIGHT = 60.00 FT
SNR REQUIRED AT THE COMMUNICATION RECEIVER INPUT = 13.00
QNR REQUIRED AT THE INTERCEPT RECEIVER INPUT = 10.00
ANTENNA POLARIZATION IS V
FREQUENCY = 300.00 MHz
TRANSMITTER ANTENNA GAIN IN THE DIRECTION OF THE COMMUNICATION LINK RECEIVER = 3.00
TRANSMITTER ANTENNA GAIN IN THE DIRECTION OF THE INTERCEPT RECEIVER ANTENNA = 1.00
INTERCEPT RECEIVER ANTENNA GAIN IN THE DIRECTION OF THE TRANSMITTER ANTENNA = 6.00
INTERCEPT RECEIVER TIME-BANDWIDTH PRODUCT = 1000.00
TRANSMISSION LINE LOSSES = 0.50 dB
CONDUCTIVITY = 0.02 mho/m
PERMITTIVITY = 25.00
INTERCEPT RECEIVER NOISE FIGURE = 6.00 dB
COMMUNICATION RECEIVER RESOLUTION BANDWIDTH = 25000.00 Hz
SPREAD SPECTRUM BANDWIDTH = 300.00 MHz
INTERCEPT RECEIVER RESOLUTION BANDWIDTH = 25000.00 Hz
INTERCEPT RECEIVER LOSS = 2.00 MHz
COMMUNICATION RECEIVER NOISE FIGURE = 10.00 dB
SURFACE REFRACTIVITY COEFFICIENT = 300.00
TERRAIN PARAMETER DELTA = 200.00

INTERCEPT RECEIVER DATA HAS BEEN CHOSEN

DUE TO THE REQUIRED SNR OF 10.00 dB AT THE RECEIVER INPUT
A RECEIVER SENSITIVITY OF -73.23 dBm IS NEEDED

***** INTERCEPT WSS=300 MHz *********

Distance (miles)	Free Space Losses (dB)	Excess Losses (dB)	Signal-to-Receiver Sensitivity: Free Space R-Squared Propagation (dB above Receiver Sensitivity)	Ground R-Squared Propagation	Ground R-Fourth Propagation
0.50	80.10	27.86	47.62	19.76	21.65
1.00	86.13	30.63	41.60	10.97	6.84
1.50	89.65	30.88	38.08	7.20	
2.00	92.15	31.14	35.59	4.44	
2.50	94.08	31.39	33.64	2.25	
3.00	95.67	31.65	32.06	0.41	
3.50	97.01	31.91	30.72		

TABULAR DATA FOR GROUND-TO-GROUND (GROUND R-FOURTH) AND GROUND-TO-AIR (GROUND R-SQUARED) COMMUNICATION LINK PERFORMANCE AS A FUNCTION OF TRANSMIT POWER (for Figures 3.7 a and b, respectively)

TRANSMITTER ANTENNA HEIGHT = 10.00 FT
TRANSMITTER ERP = 1.00 Watts
COMMUNICATION RECEIVER LOSS = 2.00 dB
COMMUNICATION RECEIVER ANTENNA GAIN IN THE DIRECTION OF THE TRANSMITTER = 3.00
COMMUNICATION RECEIVER ANTENNA HEIGHT = 10.00 FT
INTERCEPT RECEIVER ANTENNA HEIGHT = 60.00 FT
SNR REQUIRED AT THE COMMUNICATION RECEIVER INPUT = 13.00
QNR REQUIRED AT THE INTERCEPT RECEIVER INPUT = 10.00
ANTENNA POLARIZATION IS V
FREQUENCY = 300.00 MHz
TRANSMITTER ANTENNA GAIN IN THE DIRECTION OF THE COMMUNICATION LINK RECEIVER = 3.00
TRANSMITTER ANTENNA GAIN IN THE DIRECTION OF THE INTERCEPT RECEIVER ANTENNA = 1.00
INTERCEPT RECEIVER ANTENNA GAIN IN THE DIRECTION OF THE TRANSMITTER ANTENNA = 6.00
INTERCEPT RECEIVER TIME-BANDWIDTH PRODUCT = 1000.00
TRANSMISSION LINE LOSSES = 0.50 dB
CONDUCTIVITY = 0.02 mho/m
PERMITTIVITY = 25.00
INTERCEPT RECEIVER NOISE FIGURE = 6.00 dB
COMMUNICATION RECEIVER RESOLUTION BANDWIDTH = 25000.00 Hz
SPREAD SPECTRUM BANDWIDTH = 100.00 MHz
INTERCEPT RECEIVER RESOLUTION BANDWIDTH = 25000.00 Hz
INTERCEPT RECEIVER LOSS = 2.00 MHz
COMMUNICATION RECEIVER NOISE FIGURE = 10.00 dB
SURFACE REFRACTIVITY COEFFICIENT = 300.00
TERRAIN PARAMETER DELTA = 200.00

COMMUNICATIONS RECEIVER DATA HAS BEEN CHOSEN

DUE TO THE REQUIRED SNR OF 13.00 dB AT THE RECEIVER INPUT
A RECEIVER SENSITIVITY OF -107.02 dBm IS NEEDED

****** COMMUNICATIONS TXPWR=1 Watt ******

Distance	Free Space Losses	Excess Losses	Signal-to-Receiver Sensitivity: Free Space R-Squared Propagation	Ground R-Squared Propagation	Ground R-Fourth Propagation
(miles)	(dB)	(dB)	(dB above Receiver Sensitivity)		
0.50	80.10	36.81	60.42	23.61	25.50
1.00	86.13	37.07	54.40	17.33	13.19
1.50	89.65	37.33	50.87	13.54	5.89
2.00	92.15	37.59	48.37	10.78	0.63
2.50	94.08	37.85	46.44	8.58	
3.00	95.67	38.12	44.85	6.74	
3.50	97.01	38.38	43.51	5.13	
4.00	98.17	38.64	42.35	3.71	
4.50	99.19	38.90	41.33	2.43	
5.00	100.10	39.17	40.42	1.25	
5.50	100.93	39.43	39.59	0.16	
6.00	101.69	39.69	38.83		

TRANSMITTER ANTENNA HEIGHT = 10.00 FT
TRANSMITTER ERP = 10.00 Watts
COMMUNICATION RECEIVER LOSS = 2.00 dB
COMMUNICATION RECEIVER ANTENNA GAIN IN THE DIRECTION OF THE TRANSMITTER = 3.00
COMMUNICATION RECEIVER ANTENNA HEIGHT = 10.00 FT
INTERCEPT RECEIVER ANTENNA HEIGHT = 60.00 FT
SNR REQUIRED AT THE COMMUNICATION RECEIVER INPUT = 13.00
QNR REQUIRED AT THE INTERCEPT RECEIVER INPUT = 10.00
ANTENNA POLARIZATION IS V
FREQUENCY = 300.00 MHz
TRANSMITTER ANTENNA GAIN IN THE DIRECTION OF THE COMMUNICATION LINK RECEIVER = 3.00
TRANSMITTER ANTENNA GAIN IN THE DIRECTION OF THE INTERCEPT RECEIVER ANTENNA = 1.00
INTERCEPT RECEIVER ANTENNA GAIN IN THE DIRECTION OF THE TRANSMITTER ANTENNA = 6.00
INTERCEPT RECEIVER TIME-BANDWIDTH PRODUCT = 1000.00
TRANSMISSION LINE LOSSES = 0.50 dB
CONDUCTIVITY = 0.02 mho/m
PERMITTIVITY = 25.00
INTERCEPT RECEIVER NOISE FIGURE = 6.00 dB
COMMUNICATION RECEIVER RESOLUTION BANDWIDTH = 25000.00 Hz
SPREAD SPECTRUM BANDWIDTH = 100.00 MHz
INTERCEPT RECEIVER RESOLUTION BANDWIDTH = 25000.00 Hz
INTERCEPT RECEIVER LOSS = 2.00 MHz
COMMUNICATION RECEIVER NOISE FIGURE = 10.00 dB
SURFACE REFRACTIVITY COEFFICIENT = 300.00
TERRAIN PARAMETER DELTA = 200.00

COMMUNICATIONS RECEIVER DATA HAS BEEN CHOSEN

DUE TO THE REQUIRED SNR OF 13.00 dB AT THE RECEIVER INPUT
A RECEIVER SENSITIVITY OF -107.02 dBm IS NEEDED

****** COMMUNICATIONS TXPWR=10 Watts ******

Distance (miles)	Free Space Losses (dB)	Excess Losses (dB)	Signal-to-Receiver Sensitivity: Free Space R-Squared Propagation (dB above Receiver Sensitivity)	Ground R-Squared Propagation	Ground R-Fourth Propagation
0.50	80.10	36.81	70.42	33.61	35.50
1.00	86.13	37.07	64.40	27.33	23.19
1.50	89.65	37.33	60.87	23.54	15.89
2.00	92.15	37.59	58.37	20.78	10.63
2.50	94.08	37.85	56.44	18.58	6.49
3.00	95.67	38.12	54.85	16.74	3.06
3.50	97.01	38.38	53.51	15.13	0.12
4.00	98.17	38.64	52.35	13.71	
4.50	99.19	38.90	51.33	12.43	
5.00	100.10	39.17	50.42	11.25	
5.50	100.93	39.43	49.59	10.16	
6.00	101.69	39.63	48.83	9.14	
6.50	102.38	39.95	48.14	8.19	

7.00	103.03	40.21	47.49	7.28
7.50	103.63	40.48	46.89	6.42
8.00	104.19	40.74	46.33	5.60
8.50	104.71	41.00	45.81	4.81
9.00	105.21	41.26	45.31	4.05
9.50	105.68	41.52	44.84	3.32
10.00	106.13	41.79	44.40	2.61
10.50	106.55	42.05	43.97	1.92
11.00	106.95	42.31	43.57	1.26
11.50	107.34	42.57	43.18	0.61
12.00	107.71	42.83	42.81	

TRANSMITTER ANTENNA HEIGHT = 10.00 FT
TRANSMITTER EPP = 100.00 Watts
COMMUNICATION RECEIVER LOSS = 2.00 dB
COMMUNICATION RECEIVER ANTENNA GAIN IN THE DIRECTION OF THE TRANSMITTER = 3.00
COMMUNICATION RECEIVER ANTENNA HEIGHT = 10.00 FT
INTERCEPT RECEIVER ANTENNA HEIGHT = 60.00 FT
SNR REQUIRED AT THE COMMUNICATION RECEIVER INPUT = 13.00
QNR REQUIRED AT THE INTERCEPT RECEIVER INPUT = 10.00
ANTENNA POLARIZATION IS V
FREQUENCY = 300.00 MHz
TRANSMITTER ANTENNA GAIN IN THE DIRECTION OF THE COMMUNICATION LINK RECEIVER = 3.00
TRANSMITTER ANTENNA GAIN IN THE DIRECTION OF THE INTERCEPT RECEIVER ANTENNA = 1.00
INTERCEPT RECEIVER ANTENNA GAIN IN THE DIRECTION OF THE TRANSMITTER ANTENNA = 6.00
INTERCEPT RECEIVER TIME-BANDWIDTH PRODUCT = 1000.00
TRANSMISSION LINE LOSSES = 0.50 dB
CONDUCTIVITY = 0.02 mho/m
PERMITTIVITY = 25.00
INTERCEPT RECEIVER NOISE FIGURE = 6.00 dB
COMMUNICATION RECEIVER RESOLUTION BANDWIDTH = 25000.00 Hz
SPREAD SPECTRUM BANDWIDTH = 100.00 MHz
INTERCEPT RECEIVER RESOLUTION BANDWIDTH = 25000.00 Hz
INTERCEPT RECEIVER LOSS = 2.00 MHz
COMMUNICATION RECEIVER NOISE FIGURE = 10.00 dB
SURFACE REFRACTIVITY COEFFICIENT = 300.00
TERRAIN PARAMETER DELTA = 200.00

COMMUNICATIONS RECEIVER DATA HAS BEEN CHOSEN

DUE TO THE REQUIRED SNR OF 13.00 dB AT THE RECEIVER INPUT
A RECEIVER SENSITIVITY OF -107.02 dBm IS NEEDED

****** COMMUNICATIONS TXPWR=100 Watts ******

Distance (miles)	Free Space Losses (dB)	Excess Losses (dB)	Signal-to-Receiver Sensitivity: Free Space R-Squared Propagation (dB above Receiver Sensitivity)	Ground R-Squared Propagation	Ground R-Fourth Propagation
0.50	80.10	36.81	80.42	43.61	45.50
1.00	86.13	37.07	74.40	37.33	33.19
1.50	89.65	37.33	70.87	33.54	25.89
2.00	92.15	37.59	68.37	30.78	20.63
2.50	94.08	37.85	66.44	28.58	16.49
3.00	95.67	38.12	64.85	26.74	13.06
3.50	97.01	38.38	63.51	25.13	10.12
4.00	98.17	38.64	62.35	23.71	7.54
4.50	99.19	38.90	61.33	22.43	5.23
5.00	100.10	39.17	60.42	21.25	3.14
5.50	100.93	39.43	59.59	20.16	1.22
6.00	101.69	39.69	58.83	19.14	
6.50	102.38	39.95	58.14	18.19	

7.00	103.03	40.21	57.49	17.28
7.50	103.63	40.48	56.89	16.42
8.00	104.19	40.74	56.33	15.60
8.50	104.71	41.00	55.81	14.81
9.00	105.21	41.26	55.31	14.05
9.50	105.68	41.52	54.84	13.32
10.00	106.13	41.79	54.40	12.61
10.50	106.55	42.05	53.97	11.92
11.00	106.95	42.31	53.57	11.26
11.50	107.34	42.57	53.18	10.61
12.00	107.71	42.83	52.81	9.98
12.50	108.06	43.10	52.46	9.36
13.00	108.40	43.36	52.12	8.76
13.50	108.73	43.62	51.79	8.17
14.00	109.05	43.88	51.47	7.59
14.50	109.35	44.15	51.17	7.02
15.00	109.65	44.41	50.87	6.47
15.50	109.93	44.67	50.59	5.92
16.00	110.21	44.93	50.31	5.38
16.50	110.48	45.19	50.05	4.85
17.00	110.73	45.46	49.79	4.33
17.50	110.99	45.72	49.53	3.82
18.00	111.23	45.98	49.29	3.31
18.50	111.47	46.24	49.05	2.81
19.00	111.70	46.50	48.82	2.32
19.50	111.93	46.77	48.59	1.83
20.00	112.15	47.03	48.37	1.35
20.50	112.36	47.29	48.16	0.87
21.00	112.57	47.55	47.95	0.40
21.50	112.77	47.81	47.75	

TABULAR DATA FOR GROUND-TO-GROUND (GROUND R-FOURTH)
AND AIR-TO-GROUND (GROUND R-SQUARED) INTERCEPT LINK
PERFORMANCE AS A FUNCTION OF TRANSMIT POWER
(for Figures 3.8 a and b, respectively)

```
TRANSMITTER ANTENNA HEIGHT =   10.00 FT
TRANSMITTER ERP =      1.00 Watts
COMMUNICATION RECEIVER LOSS =     2.00 dB
COMMUNICATION RECEIVER ANTENNA GAIN IN THE DIRECTION OF THE TRANSMITTER =     3.00
COMMUNICATION RECEIVER ANTENNA HEIGHT =    10.00 FT
INTERCEPT RECEIVER ANTENNA HEIGHT =    60.00 FT
SNR REQUIRED AT THE COMMUNICATION RECEIVER INPUT =    13.00
QNR REQUIRED AT THE INTERCEPT RECEIVER INPUT =    10.00
ANTENNA POLARIZATION IS V
FREQUENCY = 300.00 MHz
TRANSMITTER ANTENNA GAIN IN THE DIRECTION OF THE COMMUNICATION LINK RECEIVER =     3.00
TRANSMITTER ANTENNA GAIN IN THE DIRECTION OF THE INTERCEPT RECEIVER ANTENNA =     1.00
INTERCEPT RECEIVER ANTENNA GAIN IN THE DIRECTION OF THE TRANSMITTER ANTENNA =     6.00
INTERCEPT RECEIVER TIME-BANDWIDTH PRODUCT = 1000.00
TRANSMISSION LINE LOSSES =     0.50 dB
CONDUCTIVITY =     0.02 mho/m
PERMITTIVITY =    25.00
INTERCEPT RECEIVER NOISE FIGURE =     6.00 dB
COMMUNICATION RECEIVER RESOLUTION BANDWIDTH = 25000.00 Hz
SPREAD SPECTRUM BANDWIDTH =  100.00 MHz
INTERCEPT RECEIVER RESOLUTION BANDWIDTH = 25000.00 Hz
INTERCEPT RECEIVER LOSS =     2.00 MHz
COMMUNICATION RECEIVER NOISE FIGURE =    10.00 dB
SURFACE REFRACTIVITY COEFFICIENT -  300.00
TERRAIN PARAMETER DELTA =  200.00


INTERCEPT RECEIVER DATA HAS BEEN CHOSEN


DUE TO THE REQUIRED SNR OF   10.00 dB AT THE RECEIVER INPUT
A RECEIVER SENSITIVITY OF  -78.00 dBm IS NEEDED


******* INTEPCEPT  TXPWR=1 Watt  *******
```

Distance (miles)	Free Space Losses (dB)	Excess Losses (dB)	Signal-to-Receiver Sensitivity (dB above Receiver Sensitivity): Free Space R-Squared Propagation	Ground R-Squared Propagation	Ground R-Fourth Propagation
0.50	80.10	27.86	32.40	4.53	6.42
1.00	86.13	30.63	26.37		

```
TRANSMITTER ANTENNA HEIGHT =   10.00 FT
TRANSMITTER ERP =    10.00 Watts
COMMUNICATION RECEIVER LOSS =     2.00 dB
COMMUNICATION RECEIVER ANTENNA GAIN IN THE DIRECTION OF THE TRANSMITTER =    3.00
COMMUNICATION RECEIVER ANTENNA HEIGHT =   10.00 FT
INTERCEPT RECEIVER ANTENNA HEIGHT =   60.00 FT
SNR REQUIRED AT THE COMMUNICATION RECEIVER INPUT =   13.00
QNR REQUIRED AT THE INTERCEPT RECEIVER INPUT =   10.00
ANTENNA POLARIZATION IS V
FREQUENCY = 300.00 MHz
TRANSMITTER ANTENNA GAIN IN THE DIRECTION OF THE COMMUNICATION LINK RECEIVER =    3.00
TRANSMITTER ANTENNA GAIN IN THE DIRECTION OF THE INTERCEPT RECEIVER ANTENNA =    1.00
INTERCEPT RECEIVER ANTENNA GAIN IN THE DIRECTION OF THE TRANSMITTER ANTENNA =    6.00
INTERCEPT RECEIVER TIME-BANDWIDTH PRODUCT = 1000.00
TRANSMISSION LINE LOSSES =    0.50 dB
CONDUCTIVITY =    0.02 mho/m
PERMITTIVITY =   25.00
INTERCEPT RECEIVER NOISE FIGURE =    6.00 dB
COMMUNICATION RECEIVER RESOLUTION BANDWIDTH = 25000.00 Hz
SPREAD SPECTRUM BANDWIDTH =  100.00 MHz
INTERCEPT RECEIVER RESOLUTION BANDWIDTH = 25000.00 Hz
INTERCEPT RECEIVER LOSS =    2.00 MHz
COMMUNICATION RECEIVER NOISE FIGURE =   10.00 dB
SURFACE REFRACTIVITY COEFFICIENT =  300.00
TERRAIN PARAMETER DELTA =  200.00


INTERCEPT RECEIVER DATA HAS BEEN CHOSEN


DUE TO THE REQUIRED SNR OF   10.00 dB AT THE RECEIVER INPUT
A RECEIVER SENSITIVITY OF  -78.00 dBm IS NEEDED


****** INTERCEPT  TXPWR=10 Watts  ******
```

Distance (miles)	Free Space Losses (dB)	Excess Losses (dB)	Signal-to-Receiver Sensitivity: Free Space R-Squared Propagation (dB above Receiver Sensitivity)	Ground R-Squared Propagation	Ground R-Fourth Propagation
0.50	80.10	27.86	42.40	14.53	16.42
1.00	86.13	30.63	36.37	5.75	1.61
1.50	89.65	30.88	32.85	1.97	
2.00	92.15	31.14	30.35		

TRANSMITTER ANTENNA HEIGHT = 10.00 FT
TRANSMITTER ERP = 100.00 Watts
COMMUNICATION RECEIVER LOSS = 2.00 dB
COMMUNICATION RECEIVER ANTENNA GAIN IN THE DIRECTION OF THE TRANSMITTER = 3.00
COMMUNICATION RECEIVER ANTENNA HEIGHT = 10.00 FT
INTERCEPT RECEIVER ANTENNA HEIGHT = 60.00 FT
SNR REQUIRED AT THE COMMUNICATION RECEIVER INPUT = 13.00
QNR REQUIRED AT THE INTERCEPT RECEIVER INPUT = 10.00
ANTENNA POLARIZATION IS V
FREQUENCY = 300.00 MHz
TRANSMITTER ANTENNA GAIN IN THE DIRECTION OF THE COMMUNICATION LINK RECEIVER = 3.00
TRANSMITTER ANTENNA GAIN IN THE DIRECTION OF THE INTERCEPT RECEIVER ANTENNA = 1.00
INTERCEPT RECEIVER ANTENNA GAIN IN THE DIRECTION OF THE TRANSMITTER ANTENNA = 6.00
INTERCEPT RECEIVER TIME-BANDWIDTH PRODUCT = 1000.00
TRANSMISSION LINE LOSSES = 0.50 dB
CONDUCTIVITY = 0.02 mho/m
PERMITTIVITY = 25.00
INTERCEPT RECEIVER NOISE FIGURE = 6.00 dB
COMMUNICATION RECEIVER RESOLUTION BANDWIDTH = 25000.00 Hz
SPREAD SPECTRUM BANDWIDTH = 100.00 MHz
INTERCEPT RECEIVER RESOLUTION BANDWIDTH = 25000.00 Hz
INTERCEPT RECEIVER LOSS = 2.00 MHz
COMMUNICATION RECEIVER NOISE FIGURE = 10.00 dB
SURFACE REFRACTIVITY COEFFICIENT = 300.00
TERRAIN PARAMETER DELTA = 200.00

INTERCEPT RECEIVER DATA HAS BEEN CHOSEN

DUE TO THE REQUIRED SNR OF 10.00 dB AT THE RECEIVER INPUT
A RECEIVER SENSITIVITY OF -78.00 dBm IS NEEDED

****** INTERCEPT TXPWR=100 Watts ******

Distance	Free Space Losses	Excess Losses	Signal-to-Receiver Sensitivity: Free Space R-Squared Propagation	Ground R-Squared Propagation	Ground R-Fourth Propagation
(miles)	(dB)	(dB)	(dB above Receiver Sensitivity)		
0.50	80.10	27.86	52.40	24.53	26.42
1.00	86.13	30.63	46.37	15.75	11.61
1.50	89.65	30.88	42.85	11.97	4.31
2.00	92.15	31.14	40.35	9.21	
2.50	94.08	31.39	38.42	7.02	
3.00	95.67	31.65	36.83	5.18	
3.50	97.01	31.91	35.49	3.59	
4.00	98.17	32.16	34.33	2.17	
4.50	99.19	32.42	33.31	0.89	
5.00	100.10	32.67	32.40		

TABULAR DATA FOR GROUND-TO-AIR COMMUNICATION LINK
PERFORMANCE AS A FUNCTION OF SURFACE REFRACTIVITY COEFFICIENTS
(for Figure 3.9)

TRANSMITTER ANTENNA HEIGHT = 10.00 FT
TRANSMITTER ERP = 100.00 Watts
COMMUNICATION RECEIVER LOSS = 2.00 dB
COMMUNICATION RECEIVER ANTENNA GAIN IN THE DIRECTION OF THE TRANSMITTER = 3.00
COMMUNICATION RECEIVER ANTENNA HEIGHT = 10.00 FT
INTERCEPT RECEIVER ANTENNA HEIGHT = 60.00 FT
SNR REQUIRED AT THE COMMUNICATION RECEIVER INPUT = 13.00
SNR REQUIRED AT THE INTERCEPT RECEIVER INPUT = 10.00
ANTENNA POLARIZATION IS V
FREQUENCY = 300.00 MHz
TRANSMITTER ANTENNA GAIN IN THE DIRECTION OF THE COMMUNICATION LINK RECEIVER = 3.00
TRANSMITTER ANTENNA GAIN IN THE DIRECTION OF THE INTERCEPT RECEIVER ANTENNA = 1.00
INTERCEPT RECEIVER ANTENNA GAIN IN THE DIRECTION OF THE TRANSMITTER ANTENNA = 6.00
INTERCEPT RECEIVER TIME BANDWIDTH PRODUCT = 1000.00
TRANSMISSION LINE LOSSES = 0.50 dB
CONDUCTIVITY = 0.02 mho/m
PERMITTIVITY = 25.00
INTERCEPT RECEIVER NOISE FIGURE = 6.00 dB
COMMUNICATION RECEIVER RESOLUTION BANDWIDTH = 25000.00 Hz
SPREAD SPECTRUM BANDWIDTH = 100.00 MHz
INTERCEPT RECEIVER RESOLUTION BANDWIDTH - 25000.00 Hz
INTERCEPT RECEIVER LOSS = 2.00 MHz
COMMUNICATION RECEIVER NOISE FIGURE = 10.00 dB
SURFACE REFRACTIVITY COEFFICIENT = 250.00
TERRAIN PARAMETER DELTA = 200.00

COMMUNICATIONS RECEIVER DATA HAS BEEN CHOSEN

DUE TO THE REQUIRED SNR OF 13.00 dB AT THE RECEIVER INPUT
A RECEIVER SENSITIVITY OF -107.02 dBm IS NEEDED

***** COMMS NS=250 *****

Distance (miles)	Free Space Losses (dB)	Excess Losses (dB)	Signal-to-Receiver Sensitivity: Free Space R-Squared Propagation (dB above Receiver Sensitivity)	Ground R-Squared Propagation	Ground R-Fourth Propagation
0.50	80.10	37.06	80.42	43.35	45.24
1.00	86.13	37.34	74.40	37.05	32.92
1.50	89.65	37.62	70.87	33.26	25.60
2.00	92.15	37.89	68.37	30.48	20.33
2.50	94.08	38.17	66.44	28.27	16.18
3.00	95.67	38.44	64.85	26.41	12.73
3.50	97.01	38.72	63.51	24.79	9.78
4.00	98.17	39.00	62.35	23.36	7.18
4.50	99.19	39.27	61.33	22.06	4.86
5.00	100.10	39.55	60.42	20.87	2.75
5.50	100.93	39.82	59.59	19.76	0.82
6.00	101.69	40.10	58.83	18.73	
6.50	10[illegible].28	40.38	58.14	17.76	

7.00	103.03	40.65	57.49	16.84
7.50	103.63	40.93	56.89	15.96
8.00	104.19	41.21	56.33	15.13
8.50	104.71	41.48	55.81	14.33
9.00	105.21	41.76	55.31	13.55
9.50	105.68	42.03	54.84	12.81
10.00	106.13	42.31	54.40	12.09
10.50	106.55	42.59	53.97	11.39
11.00	106.95	42.86	53.57	10.71
11.50	107.34	43.14	53.18	10.04
12.00	107.71	43.41	52.81	9.40
12.50	108.06	43.69	52.46	8.77
13.00	108.40	43.97	52.12	8.15
13.50	108.73	44.24	51.79	7.55
14.00	109.05	44.52	51.47	6.96
14.50	109.35	44.79	51.17	6.37
15.00	109.65	45.07	50.87	5.80
15.50	109.93	45.35	50.59	5.24
16.00	110.21	45.62	50.31	4.69
16.50	110.48	45.90	50.05	4.15
17.00	110.73	46.17	49.79	3.61
17.50	110.99	46.45	49.53	3.08
18.00	111.23	46.73	49.29	2.56
18.50	111.47	47.00	49.05	2.05
19.00	111.70	47.28	48.82	1.54
19.50	111.93	47.55	48.59	1.04
20.00	112.15	47.83	48.37	0.54
20.50	112.36	48.11	48.16	0.05
21.00	112.57	48.38	47.95	

```
TRANSMITTER ANTENNA HEIGHT =    10.00 FT
TRANSMITTER ERP =   100.00 Watts
COMMUNICATION RECEIVER LOSS =     2.00 dB
COMMUNICATION RECEIVER ANTENNA GAIN IN THE DIRECTION OF THE TRANSMITTER =     3.00
COMMUNICATION RECEIVER ANTENNA HEIGHT =    10.00 FT
INTERCEPT RECEIVER ANTENNA HEIGHT =    60.00 FT
SNR REQUIRED AT THE COMMUNICATION RECEIVER INPUT =   13.00
QNR REQUIRED AT THE INTERCEPT RECEIVER INPUT =   10.00
ANTENNA POLARIZATION IS V
FREQUENCY = 300.00 MHz
TRANSMITTER ANTENNA GAIN IN THE DIRECTION OF THE COMMUNICATION LINK RECEIVER =     3.00
TRANSMITTER ANTENNA GAIN IN THE DIRECTION OF THE INTERCEPT RECEIVER ANTENNA =    1.00
INTERCEPT RECEIVER ANTENNA GAIN IN THE DIRECTION OF THE TRANSMITTER ANTENNA =    6.00
INTERCEPT RECEIVER TIME-BANDWIDTH PRODUCT = 1000.00
TRANSMISSION LINE LOSSES =     0.50 dB
CONDUCTIVITY =     0.02 mho/m
PERMITTIVITY =    25.00
INTERCEPT RECEIVER NOISE FIGURE =     6.00 dB
COMMUNICATION RECEIVER RESOLUTION BANDWIDTH = 25000.00 Hz
SPREAD SPECTRUM BANDWIDTH =   100.00 MHz
INTERCEPT RECEIVER RESOLUTION BANDWIDTH = 25000.00 Hz
INTERCEPT RECEIVER LOSS =     2.00 MHz
COMMUNICATION RECEIVER NOISE FIGURE =    10.00 dB
SURFACE REFRACTIVITY COEFFICIENT =  300.00
TERRAIN PARAMETER DELTA =  200.00


COMMUNICATIONS RECEIVER DATA HAS BEEN CHOSEN


DUE TO THE REQUIRED SNR OF    13.00 dB AT THE RECEIVER INPUT
A RECEIVER SENSITIVITY OF -107.02 dBm IS NEEDED


*****  COMMS  NS=300  *****
```

Distance (miles)	Free Space Losses (dB)	Excess Losses (dB)	Signal-to-Receiver Sensitivity: Free Space R-Squared Propagation (dB above Receiver Sensitivity)	Ground R-Squared Propagation	Ground R-Fourth Propagation
0.50	80.10	36.81	80.42	43.61	45.50
1.00	86.13	37.07	74.40	37.33	33.19
1.50	89.65	37.33	70.87	33.54	25.89
2.00	92.15	37.59	68.37	30.78	20.63
2.50	94.08	37.85	66.44	28.58	16.49
3.00	95.67	38.12	64.85	26.74	13.06
3.50	97.01	38.38	63.51	25.13	10.12
4.00	98.17	38.64	62.35	23.71	7.54
4.50	99.19	38.90	61.33	22.43	5.23
5.00	100.10	39.17	60.42	21.25	3.14
5.50	100.93	39.43	59.59	20.16	1.22
6.00	101.69	39.69	58.83	19.14	
6.50	102.38	39.95	58.14	18.19	

7.00	103.03	40.21	57.49	17.28
7.50	103.63	40.48	56.89	16.42
8.00	104.19	40.74	56.33	15.60
8.50	104.71	41.00	55.81	14.81
9.00	105.21	41.26	55.31	14.05
9.50	105.68	41.52	54.84	13.32
10.00	106.13	41.79	54.40	12.61
10.50	106.55	42.05	53.97	11.92
11.00	106.95	42.31	53.57	11.26
11.50	107.34	42.57	53.18	10.61
12.00	107.71	42.83	52.81	9.98
12.50	108.06	43.10	52.46	9.36
13.00	108.40	43.36	52.12	8.76
13.50	108.73	43.62	51.79	8.17
14.00	109.05	43.88	51.47	7.59
14.50	109.35	44.15	51.17	7.02
15.00	109.65	44.41	50.87	6.47
15.50	109.93	44.67	50.59	5.92
16.00	110.21	44.93	50.31	5.38
16.50	110.48	45.19	50.05	4.85
17.00	110.73	45.46	49.79	4.33
17.50	110.99	45.72	49.53	3.82
18.00	111.23	45.98	49.29	3.31
18.50	111.47	46.24	49.05	2.81
19.00	111.70	46.50	48.82	2.32
19.50	111.93	46.77	48.59	1.83
20.00	112.15	47.03	48.37	1.35
20.50	112.36	47.29	48.16	0.87
21.00	112.57	47.55	47.95	0.40
21.50	112.77	47.81	47.75	

TRANSMITTER ANTENNA HEIGHT = 1Ø.ØØ FT
TRANSMITTER ERP = 1ØØ.ØØ Watts
COMMUNICATION RECEIVER LOSS = 2.ØØ dB
COMMUNICATION RECEIVER ANTENNA GAIN IN THE DIRECTION OF THE TRANSMITTER = 3.ØØ
COMMUNICATION RECEIVER ANTENNA HEIGHT = 1Ø.ØØ FT
INTERCEPT RECEIVER ANTENNA HEIGHT = 6Ø.ØØ FT
SNR REQUIRED AT THE COMMUNICATION RECEIVER INPUT = 13.ØØ
QNR REQUIRED AT THE INTERCEPT RECEIVER INPUT = 1Ø.ØØ
ANTENNA POLARIZATION IS V
FREQUENCY = 3ØØ.ØØ MHz
TRANSMITTER ANTENNA GAIN IN THE DIRECTION OF THE COMMUNICATION LINK RECEIVER = 3.ØØ
TRANSMITTER ANTENNA GAIN IN THE DIRECTION OF THE INTERCEPT RECEIVER ANTENNA = 1.ØØ
INTERCEPT RECEIVER ANTENNA GAIN IN THE DIRECTION OF THE TRANSMITTER ANTENNA = 6.ØØ
INTERCEPT RECEIVER TIME-BANDWIDTH PRODUCT = 1ØØØ.ØØ
TRANSMISSION LINE LOSSES = Ø.5Ø dB
CONDUCTIVITY = Ø.Ø2 mho/m
PERMITTIVITY = 25.ØØ
INTERCEPT RECEIVER NOISE FIGURE = 6.ØØ dB
COMMUNICATION RECEIVER RESOLUTION BANDWIDTH = 25ØØØ.ØØ Hz
SPREAD SPECTRUM BANDWIDTH = 1ØØ.ØØ MHz
INTERCEPT RECEIVER RESOLUTION BANDWIDTH = 25ØØØ.ØØ Hz
INTERCEPT RECEIVER LOSS = 2.ØØ MHz
COMMUNICATION RECEIVER NOISE FIGURE = 1Ø.ØØ dB
SURFACE REFRACTIVITY COEFFICIENT = 35Ø.ØØ
TERRAIN PARAMETER DELTA = 2ØØ.ØØ

COMMUNICATIONS RECEIVER DATA HAS BEEN CHOSEN

DUE TO THE REQUIRED SNR OF 13.ØØ dB AT THE RECEIVER INPUT
A RECEIVER SENSITIVITY OF -1Ø7.Ø2 dBm IS NEEDED

***** COMMS NS=35Ø *****

Distance (miles)	Free Space Losses (dB)	Excess Losses (dB)	Signal-to-Receiver Sensitivity: Free Space R-Squared Propagation (dB above Receiver Sensitivity)	Ground R-Squared Propagation	Ground R-Fourth Propagation
Ø.5Ø	8Ø.1Ø	36.43	8Ø.42	43.98	45.87
1.ØØ	86.13	36.68	74.4Ø	37.72	33.59
1.5Ø	89.65	36.92	7Ø.87	33.95	26.3Ø
2.ØØ	92.15	37.16	68.37	31.21	21.Ø6
2.5Ø	94.Ø8	37.41	66.44	29.Ø3	16.94
3.ØØ	95.67	37.65	64.85	27.2Ø	13.53
3.5Ø	97.Ø1	37.89	63.51	25.62	1Ø.61
4.ØØ	98.17	38.14	62.35	24.22	8.Ø4
4.5Ø	99.19	38.38	61.33	22.95	5.76
5.ØØ	1ØØ.1Ø	38.62	6Ø.42	21.79	3.68
5.5Ø	1ØØ.93	38.87	59.59	2Ø.72	1.78
6.ØØ	1Ø1.69	39.11	58.83	19.72	Ø.Ø3
6.5Ø	1Ø2.38	39.35	58.14	18.79	

7.00	103.03	39.59	57.49	17.90
7.50	103.63	39.84	56.89	17.06
8.00	104.19	40.08	56.33	16.25
8.50	104.71	40.32	55.81	15.48
9.00	105.21	40.57	55.31	14.74
9.50	105.68	40.81	54.84	14.03
10.00	106.13	41.05	54.40	13.34
10.50	106.55	41.30	53.97	12.67
11.00	106.95	41.54	53.57	12.03
11.50	107.34	41.78	53.18	11.40
12.00	107.71	42.03	52.81	10.78
12.50	108.06	42.27	52.46	10.19
13.00	108.40	42.51	52.12	9.60
13.50	108.73	42.76	51.79	9.03
14.00	109.05	43.00	51.47	8.47
14.50	109.35	43.24	51.17	7.92
15.00	109.65	43.49	50.87	7.39
15.50	109.93	43.73	50.59	6.86
16.00	110.21	43.97	50.31	6.34
16.50	110.48	44.22	50.05	5.83
17.00	110.73	44.46	49.79	5.33
17.50	110.99	44.70	49.53	4.83
18.00	111.23	44.95	49.29	4.34
18.50	111.47	45.19	49.05	3.86
19.00	111.70	45.43	48.82	3.39
19.50	111.93	45.68	48.59	2.92
20.00	112.15	45.92	48.37	2.46
20.50	112.36	46.16	48.16	2.00
21.00	112.57	46.41	47.95	1.54
21.50	112.77	46.65	47.75	1.10
22.00	112.97	46.89	47.55	0.65
22.50	113.17	47.14	47.35	0.22
23.00	113.36	47.38	47.16	

TRANSMITTER ANTENNA HEIGHT = 10.00 FT
TRANSMITTER ERP = 100.00 Watts
COMMUNICATION RECEIVER LOSS = 2.00 dB
COMMUNICATION RECEIVER ANTENNA GAIN IN THE DIRECTION OF THE TRANSMITTER = 3.00
COMMUNICATION RECEIVER ANTENNA HEIGHT = 10.00 FT
INTERCEPT RECEIVER ANTENNA HEIGHT = 60.00 FT
SNR REQUIRED AT THE COMMUNICATION RECEIVER INPUT = 13.00
QNR REQUIRED AT THE INTERCEPT RECEIVER INPUT = 10.00
ANTENNA POLARIZATION IS V
FREQUENCY = 300.00 MHz
TRANSMITTER ANTENNA GAIN IN THE DIRECTION OF THE COMMUNICATION LINK RECEIVER = 3.00
TRANSMITTER ANTENNA GAIN IN THE DIRECTION OF THE INTERCEPT RECEIVER ANTENNA = 1.00
INTERCEPT RECEIVER ANTENNA GAIN IN THE DIRECTION OF THE TRANSMITTER ANTENNA = 6.00
INTERCEPT RECEIVER TIME-BANDWIDTH PRODUCT = 1000.00
TRANSMISSION LINE LOSSES = 0.50 dB
CONDUCTIVITY = 0.02 mho/m
PERMITTIVITY = 25.00
INTERCEPT RECEIVER NOISE FIGURE = 6.00 dB
COMMUNICATION RECEIVER RESOLUTION BANDWIDTH = 25000.00 Hz
SPREAD SPECTRUM BANDWIDTH = 100.00 MHz
INTERCEPT RECEIVER RESOLUTION BANDWIDTH = 25000.00 Hz
INTERCEPT RECEIVER LOSS = 2.00 MHz
COMMUNICATION RECEIVER NOISE FIGURE = 10.00 dB
SURFACE REFRACTIVITY COEFFICIENT = 400.00
TERRAIN PARAMETER DELTA = 200.00

COMMUNICATIONS RECEIVER DATA HAS BEEN CHOSEN

DUE TO THE REQUIRED SNR OF 13.00 dB AT THE RECEIVER INPUT
A RECEIVER SENSITIVITY OF -107.02 dBm IS NEEDED

***** COMMS NS-400 *******

Distance (miles)	Free Space Losses (dB)	Excess Losses (dB)	Signal-to-Receiver Sensitivity: Free Space R-Squared Propagation	Ground R-Squared Propagation	Ground R-Fourth Propagation (dB above Receiver Sensitivity)
0.50	80.10	35.87	80.42	44.55	46.43
1.00	86.13	36.09	74.40	38.31	34.18
1.50	89.65	36.30	70.87	34.57	26.92
2.00	92.15	36.52	68.37	31.85	21.70
2.50	94.08	36.74	66.44	29.70	17.61
3.00	95.67	36.96	64.85	27.90	14.22
3.50	97.01	37.17	63.51	26.34	11.33
4.00	98.17	37.39	62.35	24.96	8.79
4.50	99.19	37.61	61.33	23.72	6.53
5.00	100.10	37.83	60.42	22.59	4.48
5.50	100.93	38.04	59.59	21.55	2.60
6.00	101.69	38.26	58.83	20.57	0.88
6.50	102.38	38.48	58.14	19.66	

7.00	103.03	38.70	57.49	18.80
7.50	103.63	38.91	56.89	17.98
8.00	104.19	39.13	56.33	17.20
8.50	104.71	39.35	55.81	16.46
9.00	105.21	39.56	55.31	15.75
9.50	105.68	39.78	54.84	15.06
10.00	106.13	40.00	54.40	14.40
10.50	106.55	40.22	53.97	13.75
11.00	106.95	40.43	53.57	13.13
11.50	107.34	40.65	53.18	12.53
12.00	107.71	40.87	52.81	11.94
12.50	108.06	41.09	52.46	11.37
13.00	108.40	41.30	52.12	10.81
13.50	108.73	41.52	51.79	10.27
14.00	109.05	41.74	51.47	9.73
14.50	109.35	41.96	51.17	9.21
15.00	109.65	42.17	50.87	8.70
15.50	109.93	42.39	50.59	8.20
16.00	110.21	42.61	50.31	7.70
16.50	110.48	42.83	50.05	7.22
17.00	110.73	43.04	49.79	6.74
17.50	110.99	43.26	49.53	6.27
18.00	111.23	43.48	49.29	5.81
18.50	111.47	43.70	49.05	5.36
19.00	111.70	43.91	48.82	4.91
19.50	111.93	44.13	48.59	4.46
20.00	112.15	44.35	48.37	4.03
20.50	112.36	44.57	48.16	3.59
21.00	112.57	44.78	47.95	3.17
21.50	112.77	45.00	47.75	2.75
22.00	112.97	45.22	47.55	2.33
22.50	113.17	45.44	47.35	1.92
23.00	113.36	45.65	47.16	1.51
23.50	113.55	45.87	46.97	1.10
24.00	113.73	46.09	46.79	0.70
24.50	113.91	46.31	46.61	0.31
25.00	114.08	46.52	46.44	

TABULAR DATA FOR GROUND-TO-GROUND COMMUNICATION LINK PERFORMANCE AS A FUNCTION OF TERRAIN RADIOGEOLOGY (for Figure 3.10)

TRANSMITTER ANTENNA HEIGHT = 10.00 FT
TRANSMITTER ERP = 100.00 Watts
COMMUNICATION RECEIVER LOSS = 2.00 dB
COMMUNICATION RECEIVER ANTENNA GAIN IN THE DIRECTION OF THE TRANSMITTER = 3.00
COMMUNICATION RECEIVER ANTENNA HEIGHT = 10.00 FT
INTERCEPT RECEIVER ANTENNA HEIGHT = 60.00 FT
SNR REQUIRED AT THE COMMUNICATION RECEIVER INPUT = 13.00
QNR REQUIRED AT THE INTERCEPT RECEIVER INPUT = 10.00
ANTENNA POLARIZATION IS V
FREQUENCY = 300.00 MHz
TRANSMITTER ANTENNA GAIN IN THE DIRECTION OF THE COMMUNICATION LINK RECEIVER = 3.00
TRANSMITTER ANTENNA GAIN IN THE DIRECTION OF THE INTERCEPT RECEIVER ANTENNA = 1.00
INTERCEPT RECEIVER ANTENNA GAIN IN THE DIRECTION OF THE TRANSMITTER ANTENNA = 6.00
INTERCEPT RECEIVER TIME-BANDWIDTH PRODUCT = 1000.00
TRANSMISSION LINE LOSSES = 0.50 dB
CONDUCTIVITY = 0.02 mho/m
PERMITTIVITY = 25.00
INTERCEPT RECEIVER NOISE FIGURE = 6.00 dB
COMMUNICATION RECEIVER RESOLUTION BANDWIDTH = 25000.00 Hz
SPREAD SPECTRUM BANDWIDTH = 100.00 MHz
INTERCEPT RECEIVER RESOLUTION BANDWIDTH = 25000.00 Hz
INTERCEPT RECEIVER LO = 2.00 MHz
COMMUNICATION RECEIVER NOISE FIGURE = 10.00 dB
SURFACE REFRACTIVITY COEFFICIENT = 300.00
TERRAIN PARAMETER DELTA = 100.00

COMMUNICATIONS RECEIVER DATA HAS BEEN CHOSEN

DUE TO THE REQUIRED SNR OF 13.00 dB AT THE RECEIVER INPUT
A RECEIVER SENSITIVITY OF -107.02 dBm IS NEEDED

***** COMMS PH-100 *****

Distance	Free Space Losses	Excess Losses	Signal-to-Receiver Sensitivity: Free Space R-Squared Propagation	Ground R-Squared Propagation	Ground R-Fourth Propagation
(miles)	(dB)	(dB)	(dB above Receiver Sensitivity)		
0.50	80.10	32.45	80.42	47.97	49.85
1.00	86.13	32.72	74.40	41.67	37.54
1.50	89.65	32.99	70.87	37.88	30.22
2.00	92.15	33.27	68.37	35.11	24.95
2.50	94.08	33.54	66.44	32.90	20.80
3.00	95.67	33.81	64.85	31.04	17.37
3.50	97.01	34.09	63.51	29.43	14.41
4.00	98.17	34.36	62.35	28.00	11.82
4.50	99.19	34.63	61.33	26.70	9.50
5.00	100.10	34.90	60.42	25.51	7.40
5.50	100.93	35.18	59.59	24.41	5.47
6.00	101.69	35.45	58.83	23.38	3.69
6.50	102.38	35.72	58.14	22.42	2.02

7.00	103.03	35.99	57.49	21.50	0.46
7.50	103.63	36.27	56.89	20.63	
8.00	104.19	36.54	56.33	19.79	
8.50	104.71	36.81	55.81	18.99	
9.00	105.21	37.08	55.31	18.23	
9.50	105.68	37.36	54.84	17.48	
10.00	106.13	37.63	54.40	16.77	
10.50	106.55	37.90	53.97	16.07	
11.00	106.95	38.18	53.57	15.39	
11.50	107.34	38.45	53.18	14.73	
12.00	107.71	38.72	52.81	14.09	
12.50	108.06	38.99	52.46	13.46	
13.00	108.40	39.27	52.12	12.85	
13.50	108.73	39.54	51.79	12.25	
14.00	109.05	39.81	51.47	11.66	
14.50	109.35	40.08	51.17	11.08	
15.00	109.65	40.36	50.87	10.52	
15.50	109.93	40.63	50.59	9.96	
16.00	110.21	40.90	50.31	9.41	
16.50	110.48	41.18	50.05	8.87	
17.00	110.73	41.45	49.79	8.34	
17.50	110.99	41.72	49.53	7.81	
18.00	111.23	41.99	49.29	7.30	
18.50	111.47	42.27	49.05	6.79	
19.00	111.70	42.54	48.82	6.28	
19.50	111.93	42.81	48.59	5.78	
20.00	112.15	43.08	48.37	5.29	
20.50	112.36	43.36	48.16	4.80	
21.00	112.57	43.63	47.95	4.32	
21.50	112.77	43.90	47.75	3.84	
22.00	112.97	44.17	47.55	3.37	
22.50	113.17	44.45	47.35	2.90	
23.00	113.36	44.72	47.16	2.44	
23.50	113.55	44.99	46.97	1.98	
24.00	113.73	45.27	46.79	1.53	
24.50	113.91	45.54	46.61	1.07	
25.00	114.08	45.81	46.44	0.63	
25.50	114.26	46.08	46.26	0.18	
26.00	114.42	46.36	46.10		

TRANSMITTER ANTENNA HEIGHT = 10.00 FT
TRANSMITTER ERP = 100.00 Watts
COMMUNICATION RECEIVER LOSS = 2.00 dB
COMMUNICATION RECEIVER ANTENNA GAIN IN THE DIRECTION OF THE TRANSMITTER = 3.00
COMMUNICATION RECEIVER ANTENNA HEIGHT = 10.00 FT
INTERCEPT RECEIVER ANTENNA HEIGHT = 60.00 FT
SNR REQUIRED AT THE COMMUNICATION RECEIVER INPUT = 13.00
QNR REQUIRED AT THE INTERCEPT RECEIVER INPUT = 10.00
ANTENNA POLARIZATION IS V
FREQUENCY = 300.00 MHz
TRANSMITTER ANTENNA GAIN IN THE DIRECTION OF THE COMMUNICATION LINK RECEIVER = 3.00
TRANSMITTER ANTENNA GAIN IN THE DIRECTION OF THE INTERCEPT RECEIVER ANTENNA = 1.00
INTERCEPT RECEIVER ANTENNA GAIN IN THE DIRECTION OF THE TRANSMITTER ANTENNA = 6.00
INTERCEPT RECEIVER TIME BANDWIDTH PRODUCT = 1000.00
TRANSMISSION LINE LOSSES = 0.50 dB
CONDUCTIVITY = 0.02 mho/m
PERMITTIVITY = 25.00
INTERCEPT RECEIVER NOISE FIGURE = 6.00 dB
COMMUNICATION RECEIVER RESOLUTION BANDWIDTH = 25000.00 Hz
SPREAD SPECTRUM BANDWIDTH = 100.00 MHz
INTERCEPT RECEIVER RESOLUTION BANDWIDTH = 25000.00 Hz
INTERCEPT RECEIVER LOSS = 2.00 MHz
COMMUNICATION RECEIVER NOISE FIGURE = 10.00 dB
SURFACE REFRACTIVITY COEFFICIENT = 300.00
TERRAIN PARAMETER DELTA = 200.00

COMMUNICATIONS RECEIVER DATA HAS BEEN CHOSEN

DUE TO THE REQUIRED SNR OF 13.00 dB AT THE RECEIVER INPUT
A RECEIVER SENSITIVITY OF -107.02 dBm IS NEEDED

***** COMMS DH=200 *****

Distance (miles)	Free Space Losses (dB)	Excess Losses (dB)	Signal-to-Receiver Sensitivity: Free Space R-Squared Propagation (dB above Receiver Sensitivity)	Ground R-Squared Propagation	Ground R-Fourth Propagation
0.50	80.10	36.81	80.42	43.61	45.50
1.00	86.13	37.07	74.40	37.33	33.19
1.50	89.65	37.33	70.87	33.54	25.89
2.00	92.15	37.59	68.37	30.78	20.63
2.50	94.08	37.85	66.44	28.58	16.49
3.00	95.67	38.12	64.85	26.74	13.06
3.50	97.01	38.38	63.51	25.13	10.12
4.00	98.17	38.64	62.35	23.71	7.54
4.50	99.19	38.90	61.33	22.43	5.23
5.00	100.10	39.17	60.42	21.25	3.14
5.50	100.93	39.43	59.59	20.16	1.22
6.00	101.69	39.69	58.83	19.14	
6.50	102.38	39.95	58.14	18.19	

7.00	103.03	40.21	57.49	17.28
7.50	103.63	40.48	56.89	16.42
8.00	104.19	40.74	56.33	15.60
8.50	104.71	41.00	55.81	14.81
9.00	105.21	41.26	55.31	14.05
9.50	105.68	41.52	54.84	13.32
10.00	106.13	41.79	54.40	12.61
10.50	106.55	42.05	53.97	11.92
11.00	106.95	42.31	53.57	11.26
11.50	107.34	42.57	53.18	10.61
12.00	107.71	42.83	52.81	9.98
12.50	108.06	43.10	52.46	9.36
13.00	108.40	43.36	52.12	8.76
13.50	108.73	43.62	51.79	8.17
14.00	109.05	43.88	51.47	7.59
14.50	109.35	44.15	51.17	7.02
15.00	109.65	44.41	50.87	6.47
15.50	109.93	44.67	50.59	5.92
16.00	110.21	44.93	50.31	5.38
16.50	110.48	45.19	50.05	4.85
17.00	110.73	45.46	49.79	4.33
17.50	110.99	45.72	49.53	3.82
18.00	111.23	45.98	49.29	3.31
18.50	111.47	46.24	49.05	2.81
19.00	111.70	46.50	48.82	2.32
19.50	111.93	46.77	48.59	1.83
20.00	112.15	47.03	48.37	1.35
20.50	112.36	47.29	48.16	0.87
21.00	112.57	47.55	47.95	0.40
21.50	112.77	47.81	47.75	

```
TRANSMITTER ANTENNA HEIGHT =   10.00 FT
TRANSMITTER ERP =   100.00 Watts
COMMUNICATION RECEIVER LOSS =     2.00 dB
COMMUNICATION RECEIVER ANTENNA GAIN IN THE DIRECTION OF THE TRANSMITTER =     3.00
COMMUNICATION RECEIVER ANTENNA HEIGHT =    10.00 FT
INTERCEPT RECEIVER ANTENNA HEIGHT =    60.00 FT
SNR REQUIRED AT THE COMMUNICATION RECEIVER INPUT =    13.00
SNR REQUIRED AT THE INTERCEPT RECEIVER INPUT =    10.00
ANTENNA POLARIZATION IS V
FREQUENCY = 300.00 MHz
TRANSMITTER ANTENNA GAIN IN THE DIRECTION OF THE COMMUNICATION LINK RECEIVER =     3.00
TRANSMITTER ANTENNA GAIN IN THE DIRECTION OF THE INTERCEPT RECEIVER ANTENNA =     1.00
INTERCEPT RECEIVER ANTENNA GAIN IN THE DIRECTION OF THE TRANSMITTER ANTENNA =     6.00
INTERCEPT RECEIVER TIME BANDWIDTH PRODUCT = 1000.00
TRANSMISSION LINE LOSSES =     0.50 dB
CONDUCTIVITY =     0.02 mho/m
PERMITTIVITY =   25.00
INTERCEPT RECEIVER NOISE FIGURE =     6.00 dB
COMMUNICATION RECEIVER RESOLUTION BANDWIDTH = 25000.00 Hz
SPREAD SPECTRUM BANDWIDTH =   100.00 MHz
INTERCEPT RECEIVER RESOLUTION BANDWIDTH = 25000.00 Hz
INTERCEPT RECEIVER LOSS =     2.00 MHz
COMMUNICATION RECEIVER NOISE FIGURE =    10.00 dB
SURFACE REFRACTIVITY COEFFICIENT =   300.00
TERRAIN PARAMETER DELTA =   300.00
```

COMMUNICATIONS RECEIVER DATA HAS BEEN CHOSEN

DUE TO THE REQUIRED SNR OF   13.00 dB AT THE RECEIVER INPUT
A RECEIVER SENSITIVITY OF -107.02 dBm IS NEEDED

*****   COMMS   DH=300   *****

Distance	Free Space Losses	Excess Losses	Signal-to-Receiver Sensitivity: Free Space R-Squared Propagation	Ground R-Squared Propagation	Ground R-Fourth Propagation
(miles)	(dB)	(dB)	(dB above Receiver Sensitivity)		
0.50	80.10	43.77	80.42	36.64	38.53
1.00	86.13	44.02	74.40	30.38	26.24
1.50	89.65	44.27	70.87	26.61	18.95
2.00	92.15	44.51	68.37	23.86	13.71
2.50	94.08	44.76	66.44	21.68	9.59
3.00	95.67	45.01	64.85	19.85	6.17
3.50	97.01	45.25	63.51	18.26	3.25
4.00	98.17	45.50	62.35	16.85	0.68
4.50	99.19	45.75	61.33	15.58	
5.00	100.10	46.00	60.42	14.42	
5.50	100.93	46.24	59.59	13.35	
6.00	101.69	46.49	58.83	12.34	
6.50	102.38	46.74	58.14	11.40	

7.00	103.03	46.98	57.49	10.51
7.50	103.63	47.23	56.89	9.66
8.00	104.19	47.48	56.33	8.86
8.50	104.71	47.72	55.81	8.08
9.00	105.21	47.97	55.31	7.34
9.50	105.68	48.22	54.84	6.62
10.00	106.13	48.47	54.40	5.93
10.50	106.55	48.71	53.97	5.26
11.00	106.95	48.96	53.57	4.61
11.50	107.34	49.21	53.18	3.97
12.00	107.71	49.45	52.81	3.36
12.50	108.06	49.70	52.46	2.75
13.00	108.40	49.95	52.12	2.17
13.50	108.73	50.20	51.79	1.59
14.00	109.05	50.44	51.47	1.03
14.50	109.35	50.69	51.17	0.48
15.00	109.65	50.94	50.87	

```
TRANSMITTER ANTENNA HEIGHT =   10.00 FT
TRANSMITTER ERP =   100.00 Watts
COMMUNICATION RECEIVER LOSS =    2.00 dB
COMMUNICATION RECEIVER ANTENNA GAIN IN THE DIRECTION OF THE TRANSMITTER =    3.00
COMMUNICATION RECEIVER ANTENNA HEIGHT =   10.00 FT
INTERCEPT RECEIVER ANTENNA HEIGHT =   60.00 FT
SNR REQUIRED AT THE COMMUNICATION RECEIVER INPUT =   13.00
QNR REQUIRED AT THE INTERCEPT RECEIVER INPUT =   10.00
ANTENNA POLARIZATION IS V
FREQUENCY = 300.00 MHz
TRANSMITTER ANTENNA GAIN IN THE DIRECTION OF THE COMMUNICATION LINK RECEIVER =    3.00
TRANSMITTER ANTENNA GAIN IN THE DIRECTION OF THE INTERCEPT RECEIVER ANTENNA =    1.00
INTERCEPT RECEIVER ANTENNA GAIN IN THE DIRECTION OF THE TRANSMITTER ANTENNA =    6.00
INTERCEPT RECEIVER TIME BANDWIDTH PRODUCT = 1000.00
TRANSMISSION LINE LOSSES =    0.50 dB
CONDUCTIVITY =    0.02 mho/m
PERMITTIVITY =   25.00
INTERCEPT RECEIVER NOISE FIGURE =    6.00 dB
COMMUNICATION RECEIVER RESOLUTION BANDWIDTH = 25000.00 Hz
SPREAD SPECTRUM BANDWIDTH =  100.00 MHz
INTERCEPT RECEIVER RESOLUTION BANDWIDTH = 25000.00 Hz
INTERCEPT RECEIVER LOSS =    2.00 MHz
COMMUNICATION RECEIVER NOISE FIGURE =   10.00 dB
SURFACE REFRACTIVITY COEFFICIENT =  300.00
TERRAIN PARAMETER DELTA =  400.00


COMMUNICATIONS RECEIVER DATA HAS BEEN CHOSEN


DUE TO THE REQUIRED SNR OF   13.00 dB AT THE RECEIVER INPUT
A RECEIVER SENSITIVITY OF -107.02 dBm IS NEEDED


*****  COMMS   DH-400  *****
```

Distance (miles)	Free Space Losses (dB)	Excess Losses (dB)	Signal-to-Receiver Sensitivity: Free Space R-Squared Propagation (dB above Receiver Sensitivity)	Ground R-Squared Propagation	Ground R-Fourth Propagation
0.50	80.10	49.93	80.42	30.49	32.38
1.00	86.13	50.16	74.40	24.23	20.10
1.50	89.65	50.40	70.87	20.47	12.82
2.00	92.15	50.64	68.37	17.74	7.58
2.50	94.08	50.88	66.44	15.56	3.47
3.00	95.67	51.11	64.85	13.74	0.06
3.50	97.01	51.35	63.51	12.16	
4.00	98.17	51.59	62.35	10.77	
4.50	99.19	51.83	61.33	9.51	
5.00	100.10	52.06	60.42	8.35	
5.50	100.93	52.30	59.59	7.29	
6.00	101.69	52.54	58.83	6.30	
6.50	102.38	52.77	58.14	5.36	

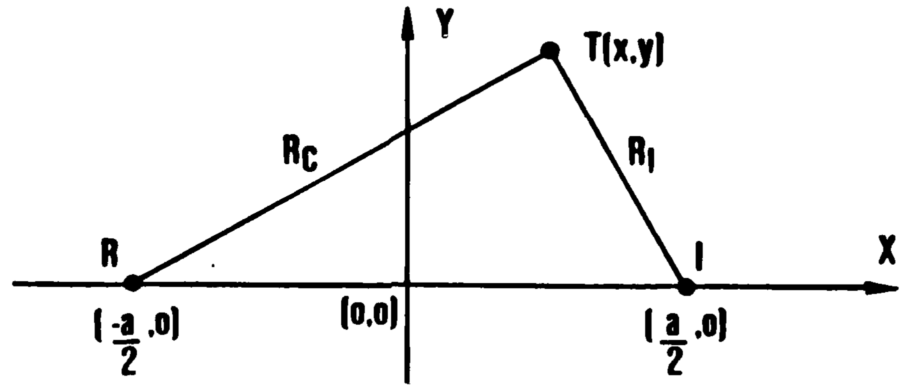
7.00	103.03	53.01	57.49	4.48
7.50	103.63	53.25	56.89	3.65
8.00	104.19	53.49	56.33	2.85
8.50	104.71	53.72	55.81	2.08
9.00	105.21	53.96	55.31	1.35
9.50	105.68	54.20	54.84	0.64
10.00	106.13	54.43	54.40	

APPENDIX C

BASIC INTERCEPT CALCULATIONS FOR DETECTABILITY CONTOURS IN SPACE

FREE SPACE ($1/R^2$) PROPAGATION

- **Communication Transmitter (T), Communication Receiver (R), and Intercept Receiver (I)**



- **Assuming All Free Space Loss**
  - **Signal Power at Comm Receiver** $= S = \dfrac{P_c G_{CR} G_{RC} \lambda^2}{(4\pi R_C)^2 L_C}$
    - **Noise Level at Comm Receiver** $= N_C = k\,TN_{Ic}\,B_{INFO}$
  - **Signal Power at Intercept Receiver** $= Q = \dfrac{P_C G_{CI} G_{IC} \lambda^2 X}{(4\pi R_I)^2 L_I}$
    - X = **Signal Suppression Factor (SSF)**
    - **Noise Level at Intercept Receiver** $= N_I = kTN_{II}\,B_{INT}$

CONTOURS OF CONSTANT RATIO OF SIGNAL-TO-NOISE RATIOS

FREE SPACE ($1/R^2$) PROPAGATION

- Signal-to-Noise Ratio at Comm Receiver $= \frac{S}{N_C} \equiv (SNR)_C$

$$= \frac{P_C G_{CR} G_{RC} \lambda^2}{(4\pi R_C)^2 L_C N_C}$$

- Signal-to-Noise Ratio at Intercept Receiver $= \frac{Q}{N_I} \equiv (SNR)_I$

$$= \frac{P_C G_{CI} G_{IC} \lambda^2 X}{(4\pi R_I)^2 L_I N_I}$$

- Ratio of Signal-to-Noise Ratios $= \frac{(SNR)_I}{(SNR)_C} \equiv \frac{I}{C}$

$$= \left[\frac{G_{CI} G_{IC} L_C N_C X}{G_{CR} G_{RC} L_I N_I}\right] \frac{R_C^2}{R_I^2} \equiv M \frac{R_C^2}{R_I^2} = M \frac{(x + a/2)^2 + y^2}{(x - a/2)^2 + y^2}$$

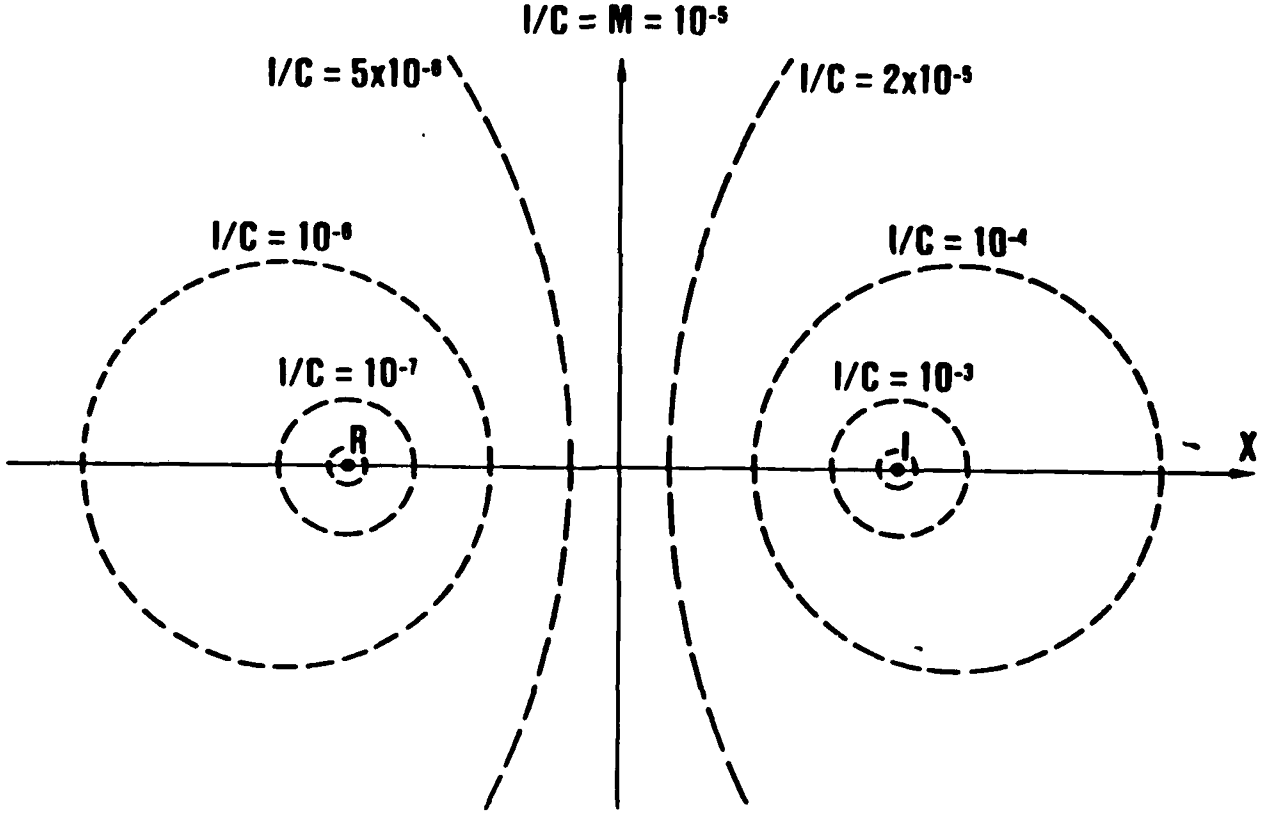
- Contours of Constant I/C are Circles
  - Center at $(x_C, 0)$ where $x_C = \frac{a}{2}\left[\frac{(I/C) + M}{(I/C) - M}\right]$
  - Radius $= \frac{a}{2}\left[\left[\frac{(I/C) + M}{(I/C) - M}\right]^2 - 1\right]^{1/2}$

EXAMPLE OF I/C CONTOURS IN SPACE

FREE SPACE $(1/R^2)$ PROPAGATION

- **ASSUMPTIONS**
  - $G_{CI} = 10^{-1}$, $G_{IC} = 10$
  - $G_{CI} = 100$, $G_{RC} = 10$
  - $L_C = L_I$, $N_C = N_I$
  - Signal Suppression Factor = $X = 10^{-2}$

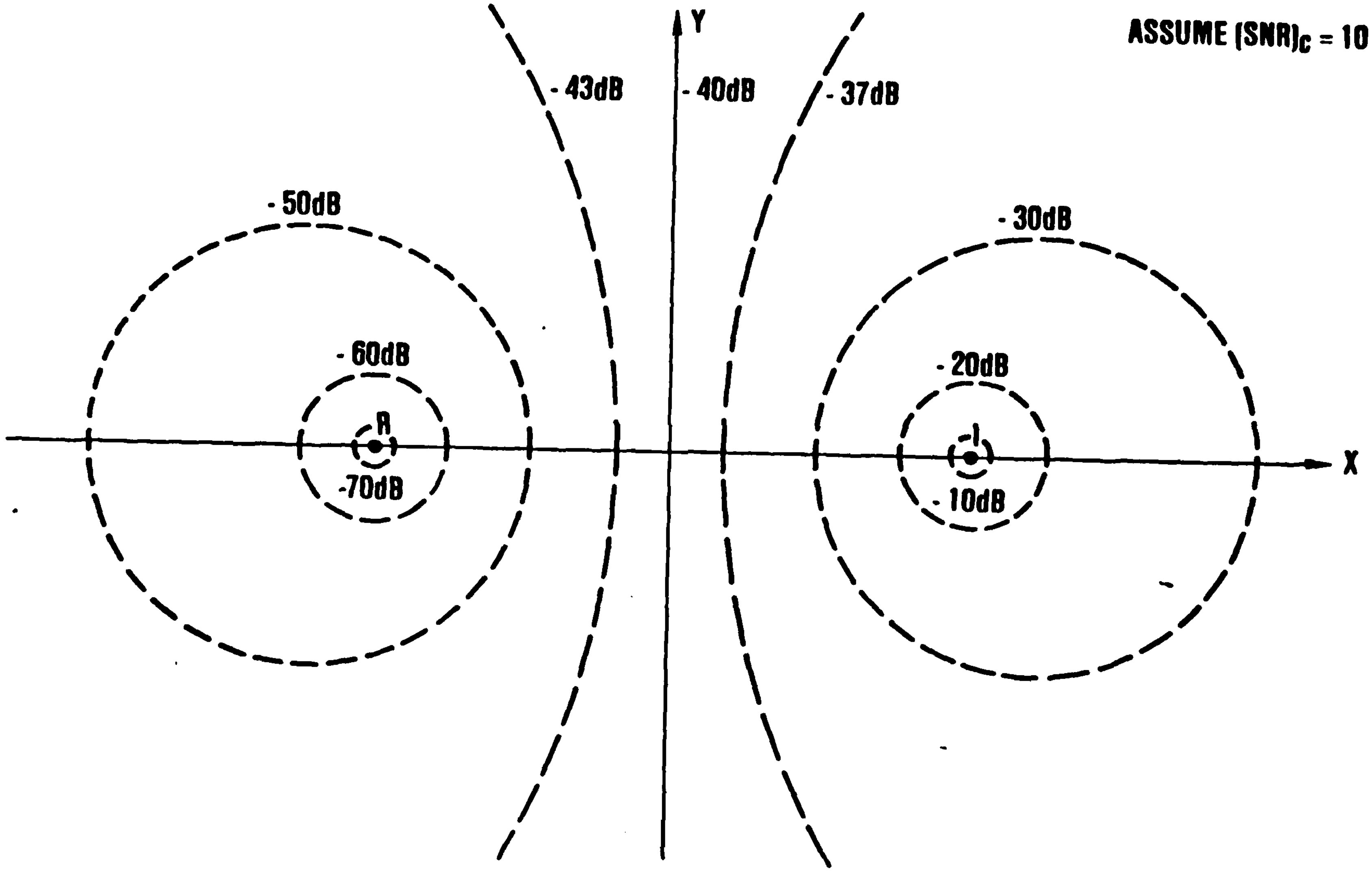
$$M = \frac{(10^{-1})(10)\,10^{-2}}{(10^{2})\,(10)} = 10^{-5}$$



CONTOURS OF CONSTANT INTERCEPT SNR

(POWER CONTROL) FREE SPACE ($1/R^2$) PROPAGATION

ASSUME $(SNR)_C = 10$



USE OR DISCLOSURE OF PROPOSAL DATA IS SUBJECT TO THE RESTRICTION ON THE TITLE PAGE OF THIS PROPOSAL

APPENDIX D

ESTABLISHING CONFIDENCE BOUNDS FOR THE INTERCEPTER

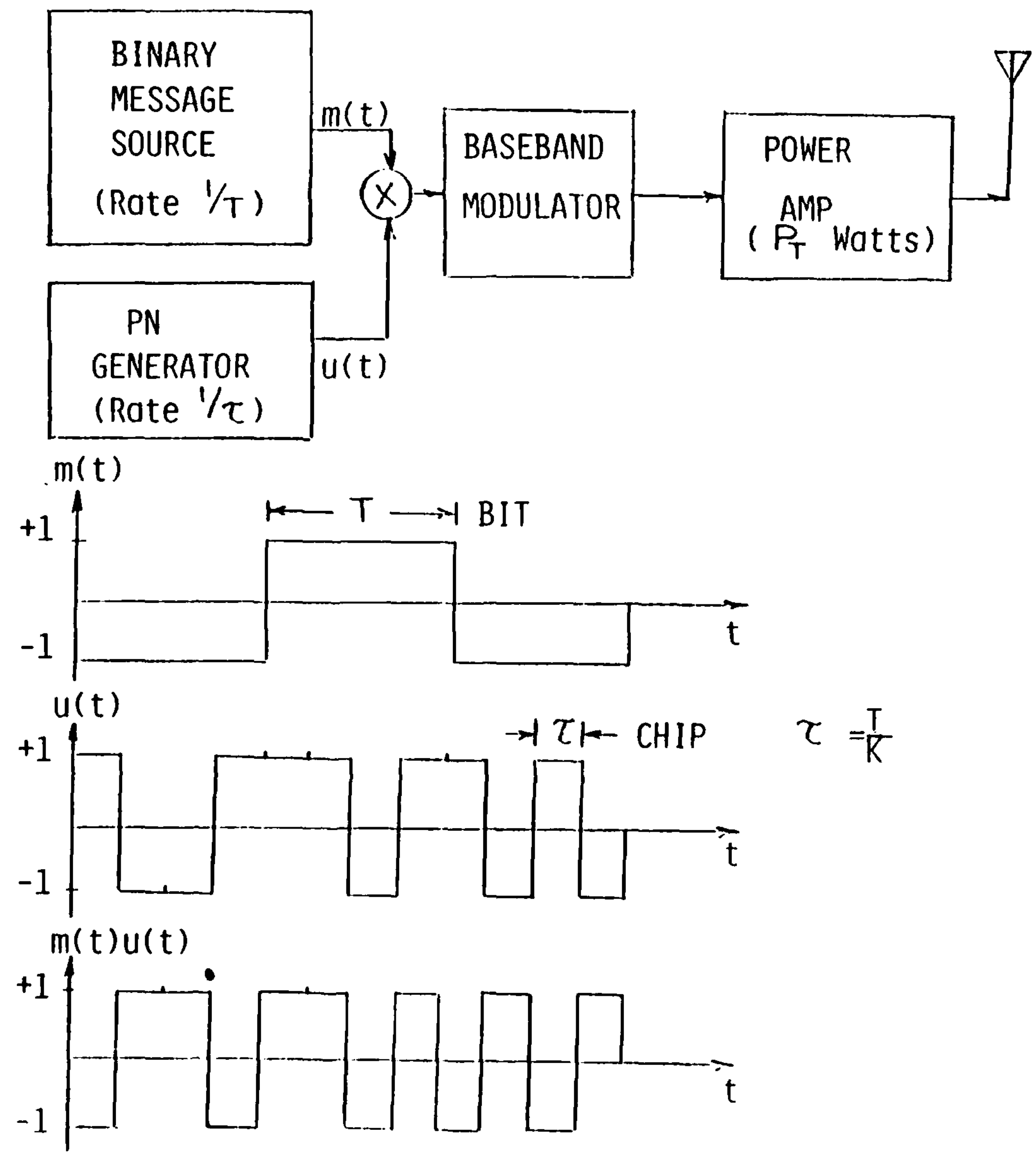
ANALYSIS OF NARROW-BAND INTERCEPT OF
DIRECT SEQUENCE, SPREAD SPECTRUM SIGNALS

OUTLINE

- Signal Spreading in Direct Sequence Systems
- Intercept of DS Signals
- Statistics of Intercept Signal-to-Noise Ratio
- Statistics of Intercept Range
- Performance of Exploitation
- Conclusions

David L. Nicholson
Special Processing Systems
E-Systems, Melpar Division

SIGNAL SPREADING AT DIRECT SEQUENCE TRANSMITTER



$\tau = \frac{T}{K}$

AVERAGE POWER DENSITY

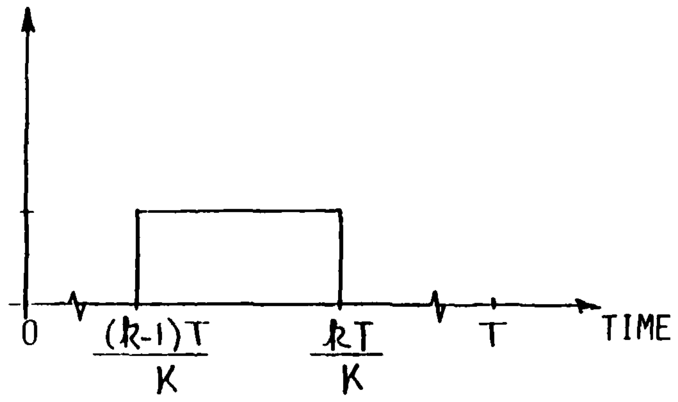
$$S(f) \cong \frac{P_T}{1/\tau} = \frac{P_T}{1/T}\,\frac{1}{K} = \frac{E_b}{K}$$

TIME DOMAIN REPRESENTATION OF BINARY PN SEGMENT

- $u(t) = \sum_{k=1}^{K} u_k \, A(t - kT/K)$

- $u_k = +1 \text{ or } -1 \text{ with } P_r = 1/2$

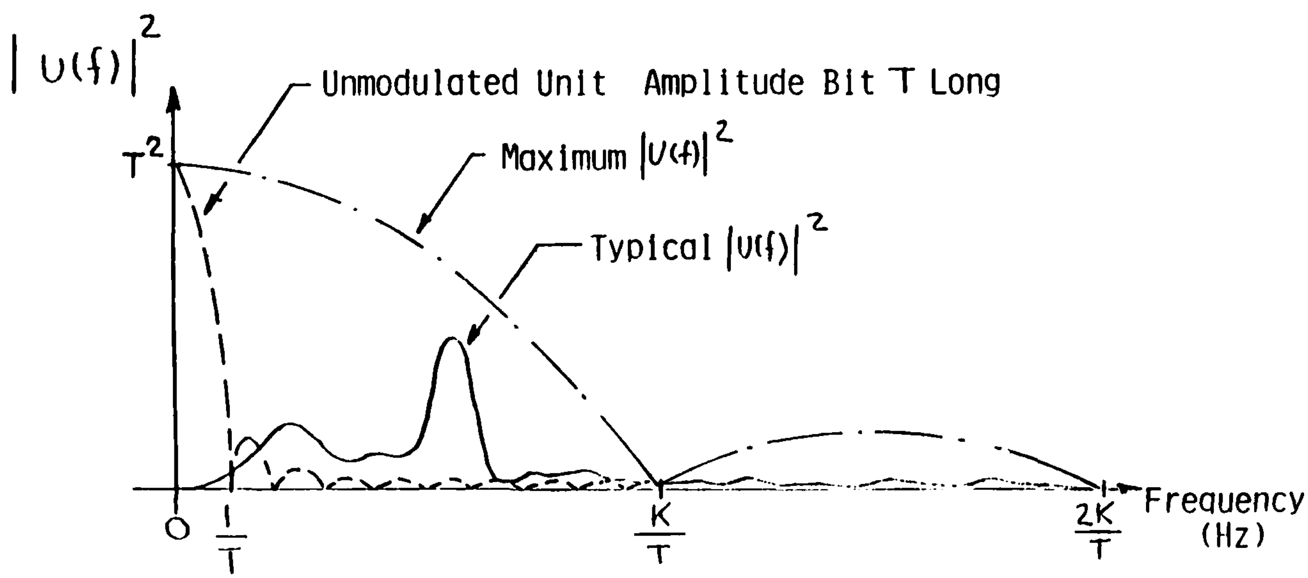
- $A(t - kT/K)$



SPREADING PROPERTIES OF SHORT SEGMENTS OF LONG M-SEQUENCES

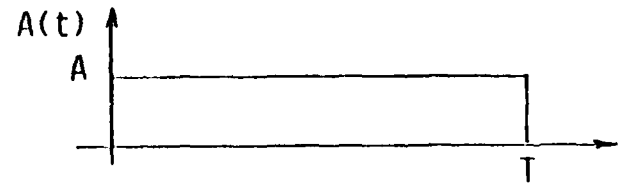
- Fourier Spectrum of $u(t)$

$$|U(f)| = T\left|\frac{\sin \pi f T/K}{\pi f T/K}\right|\left|\frac{1}{K}\sum_{k=1}^{K} u_k e^{-j\pi f(2k-1)T/K}\right|$$

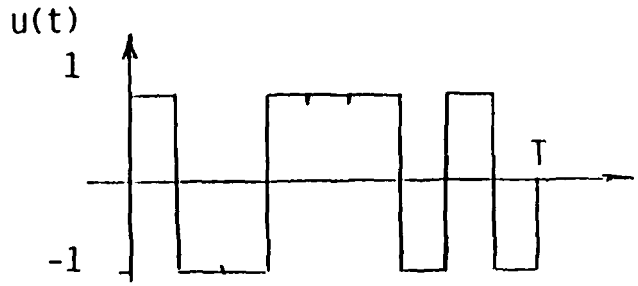


DETECTION SITUATION AT FRIENDLY RECEIVER

- Suppose Message Before LPI Modulation is $S(t) = A(t) \cos 2\pi f_c t$



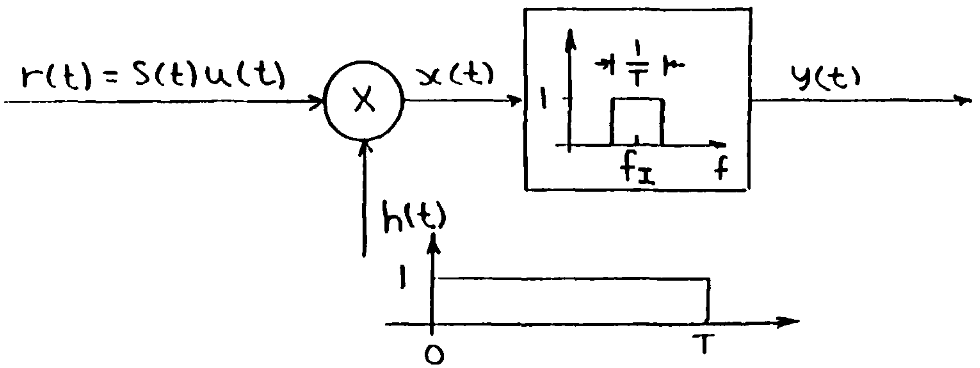
- $E_S = A^2T/2$; Bandwidth $\cong 1/T$
- LPI Modulated Signal ; $S(t)u(t)$



- $E_{SU} = A^2T/2$; Bandwidth $\cong$ Number of Chips per Bit/T
- Matched Filter Receiver Signal-to-Noise Ratio = $\dfrac{2E_S}{N_O}$

DETECTION SITUATION AT UNFRIENDLY
INTERCEPT RECEIVER

- Signals at Intercept Receiver



- $H(f) = T \dfrac{\sin \pi f T}{\pi f T}$ • $R(f) = \dfrac{AT}{2} \dfrac{\sin \pi (f \pm f_c) T/K}{\pi (f \pm f_c) T/K} \left[\dfrac{1}{K} \sum_{k=1}^{K} u_k e^{-j\pi (f \pm f_c)(2k-1)T/K} \right]$

where K equals number of chips in signal bit.

- $X(f) = \int_{-\infty}^{\infty} R(\xi) H(f-\xi) d\xi \cong R(f)$ for Narrowband Receiver.

DETECTION SITUATION AT UNFRIENDLY INTERCEPT RECEIVER

(continued)

- One-Sided Energy Density of $x(t)$ is $2\left|R(f^+)\right|^2$

- Energy at Intercept Receiver Output Equals

$$\circ\ E_y = 2\int_{f_I-\frac{1}{2T}}^{f_I+\frac{1}{2T}} \left|R(f^+)\right|^2 df \cong \frac{2}{T}\left|R(f_I^+)\right|^2$$

$$= \frac{A^2T}{2}\left[\frac{\sin\pi(f_I-f_c)T/K}{\pi(f_I-f_c)T/K}\right]^2$$

$$\times\left|\frac{1}{K}\sum_{k=1}^{K} u_k e^{-j\pi(f_I-f_c)(2k-1)T/K}\right|^2$$

- When Receiver is Tuned to Communication Carrier

$$E_y = \frac{A^2T}{2}\left[\frac{1}{K}\sum_{k=1}^{K} u_k\right]^2 \le \frac{A^2T}{2}\ ;\ E_y \text{ is Random in General}$$

SIGNAL-TO-NOISE RATIO AT AN INTERCEPT RECEIVER

- INTERCEPT Power, Q
  - $$Q(f_I) = \frac{P_T G_{TI} G_{IT}}{\left|\frac{4\pi R_I}{\lambda}\right|^2 L_I} \left[\frac{\sin \pi (f_I - f_c) T/K}{\pi (f_I - f_c) T/K}\right]^2 \left|\frac{1}{K} \sum_{k=1}^{K} u_k e^{-j\pi (f_I - f_c)(2k-1) T/K}\right|^2$$
  - $$Q(f_I = f_c) = \frac{P_T G_{TI} G_{IT}}{\left[\frac{4\pi R_I}{\lambda}\right]^2 L_I} \left[\frac{1}{K} \sum_{k=1}^{K} u_k\right]^2$$
- Intercept Receiver Noise $\quad \mathcal{K} T_o N_{f_I} \left(\frac{1}{T}\right) = N_I$
- On-Frequency Intercept Signal-to-Noise Ratio $(SNR)_I$
  - $$(SNR)_I = \frac{P_T G_{TI} G_{IT}}{\left[\frac{4\pi R_I}{\lambda}\right]^2 L_I N_I} \left[\frac{1}{K} \sum_{k=1}^{K} u_k\right]^2 \equiv (SNR)_I^* \left[\frac{1}{K} \sum_{k=1}^{K} u_k\right]^2$$

STATISTICS OF $\left[\frac{1}{K}\sum_{k=1}^{K} u_k\right]^2$

- Define $X = \frac{1}{K}\sum_{k=1}^{K} u_k$
- $X \longrightarrow$ Gaussian : Zero Mean ; Variance $= \frac{1}{K}$
  - $f_X(x) = \sqrt{\frac{K}{2\pi}}\; e^{-\frac{Kx^2}{2}}$
- $f_{X^2}(x) = \sqrt{\frac{K}{2\pi x}}\; e^{-\frac{Kx}{2}}\; U(x)$; $F_{X^2}(\alpha) = 2\,\mathrm{erf}(\sqrt{\alpha K})\,U(\alpha)$
- $f_{|X|}(x) = 2\sqrt{\frac{K}{2\pi}}\; e^{-\frac{Kx^2}{2}}\; U(x)$; $F_{|X|}(\beta) = 2\,\mathrm{erf}(\beta\sqrt{K})\,U(\beta)$

VALUES OF $2\,\mathrm{erf}(x)$

x	$2\,\mathrm{erf}(x)$
.50	.38292
1.00	.68269
1.50	.86639
1.65	.90000
2.00	.95450
2.58	.99000
3.00	.99730
3.29	.99900
3.50	.99953
3.89	.99990
4.00	.99994
4.33	.99999

INTERCEPT SNR FOR DIRECT SEQUENCE SIGNALS

- $$(SNR)_I = (SNR)_I^* \left[\frac{1}{K} \sum_{k=1}^{K} u_k \right]^2$$

  $$\leq \alpha\,(SNR)_I^* \qquad \text{with Probability} = 2\,\mathrm{erf}\left(\sqrt{\alpha K}\right)$$

- EXAMPLE #1. $\alpha = 10^{-2}$; Probability $= 2\,\mathrm{erf}\left(\frac{\sqrt{K}}{10}\right)$

  with K= 400 ; Probability = .95450

  with Probability = .99994 ; K= 1600

- EXAMPLE #2. With K=2000 find α at .9900 Confidence.

  $$\sqrt{\alpha K} = 2.58 \longrightarrow \alpha = \frac{(2.58)^2}{2000} = 3.33 \times 10^{-3} = -24.8\text{ dB}$$

INTERCEPT RANGE FOR DIRECT SEQUENCE SIGNALS

- $(SNR)_I^* = \dfrac{P_T G_{TI} G_{IT}}{\left[\dfrac{4\pi R_I^*}{\lambda}\right]^2 L_I N_I}$

- $(SNR)_{IO}^*$ = Minimum Required $(SNR)_I^* = \dfrac{P_T G_{TI} G_{IT}}{\left[\dfrac{4\pi R_{IM}^*}{\lambda}\right]^2 L_I N_I}$

- $(SNR)_I = (SNR)_{IO}^* \left(\dfrac{R_{IM}^*}{R_I}\right)^2 \left[\dfrac{1}{K} \sum_{k=1}^{K} u_k\right]^2$

- $(SNR)_{IO}^* = (SNR)_{IO}^* \left(\dfrac{R_{IM}^*}{R_{IM}}\right)^2 \left[\dfrac{1}{K} \sum_{k=1}^{K} u_k\right]^2$

- $R_{IM} = R_{IM}^* \left|\dfrac{1}{K} \sum_{k=1}^{K} u_k\right|$

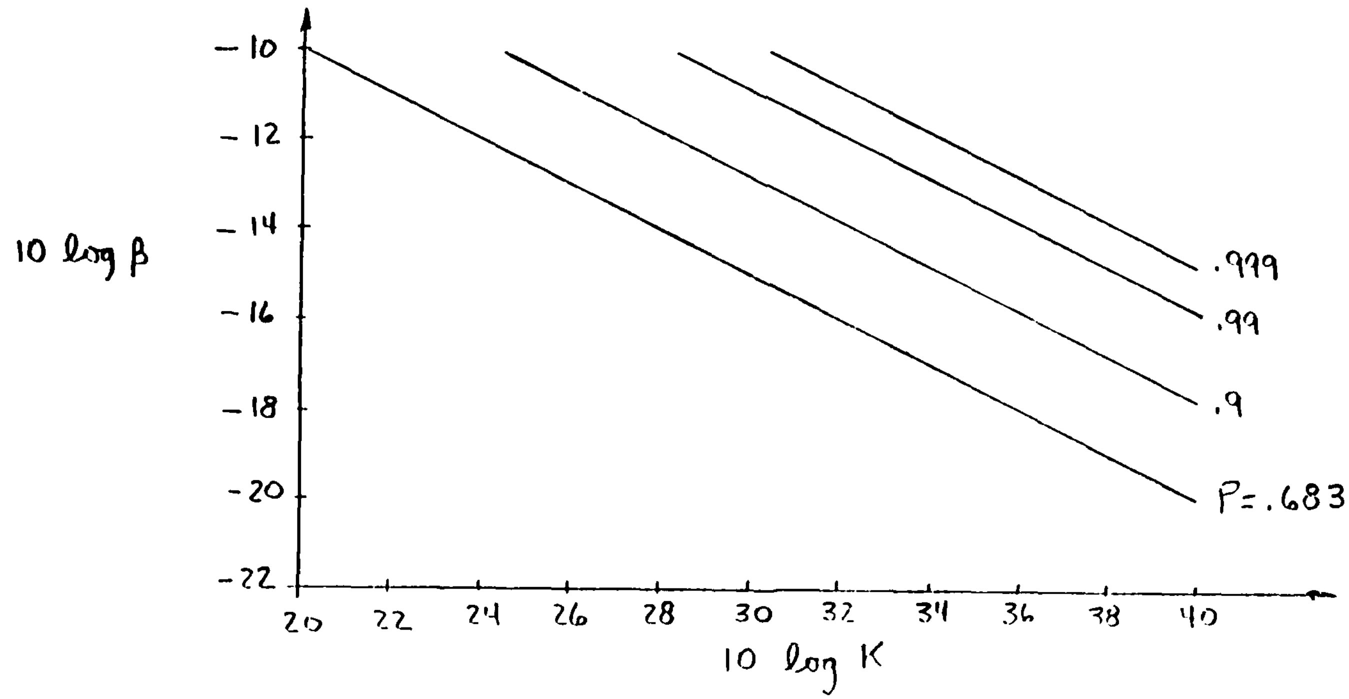
EXAMPLES OF CONFIDENCE IN INTERCEPT RANGE

- $R_{IM} \le \beta R^*_{IM}$ with Piobability = $2\,\mathrm{erf}(\beta\sqrt{K})$

  - Example #1. $\beta = 10^{-2}$, $K=2500$

    Probability $= 2\mathrm{erf}(.5) \cong .383$

- CONSTANT CONFIDENCE AT $\beta\sqrt{K} = \mathrm{erf}^{-1}(P/2)$



CONCLUSIONS

- Signal Power Spectral Density of Direct Sequence Signals is Random in General
- Intercept Variables can be Upper Bounded With a Stated Confidence or Probability
- Intercept Range can be Reduced by About 14 dB (25) with Probability .9 or about 11 dB (12.6) with Confidence of .999 by Using Direct Sequence Modulation Against Linear Spectral Analysis Receiver
- Exploitation Performance May Be Quite Poor

EXPLOITATION OF DIRECT SEQUENCE SIGNALS

- ASSUME $P_r\{\epsilon \mid E_b\} = \frac{1}{2} e^{-E_b/N_o}$ (Differentially Coherent BPSK)

  - $P_r\{\epsilon \mid X^2\} = \frac{1}{2} e^{-(SNR)_I^* X^2}$

- $P_r\{\epsilon\} = \int_0^\infty P_r\{\epsilon \mid X^2\} f_{X^2}(x)\, dx = \frac{1}{2}\sqrt{\frac{K}{2\pi}} \int_0^\infty \frac{1}{\sqrt{x}} e^{-\frac{Kx}{2}} e^{-(SNR)_I^* x} dx$

$$= \frac{1}{2\sqrt{1 + \frac{2(SNR)_I^*}{K}}}$$

- For Small $P_r\{\epsilon\}$; $P_r\{\epsilon\} \cong \frac{\sqrt{K}}{2\sqrt{2(SNR)_I^*}}$

  - For $P_r\{\epsilon\} = 10^{-3}$
    $(SNR)_I^* = 1.25 \times 10^5 K$

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